EXPERIENCE the birth of astrophysics p. 44

SEPTEMBER 2018

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ON THE COVER

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FROM THE EDITOR

BY DAVID J. EICHER

Lure of the Red Planet

Ever since the first tales of "Martians" emerged in the 19th century, humans have been fascinated by our close planetary neighbor. While we have not found life on Mars, exploring the Red Planet has become a cottage industry. It accounts for about 60 percent of the recent planetary exploration budget.

Why? Because life may exist there yet. Despite its extreme cold temperatures, Mars has ample stores of water, locked up as ice in the polar caps and believed to exist in subsurface aquifers. Perhaps life does exist on Mars — microbial life.

This month's cover story by planetary scientist Alfred McEwen highlights an active Mars mission, the Mars Reconnaissance Orbiter. Specifically, the story focuses on one of the spacecraft's instruments, the HiRISE camera, which stands for High Resolution Imaging Science Experiment. This photographic telescope is the largest ever carried on a deep space mission, some 0.5 meter in aperture.

And that's only the beginning. Featuring spectacular images from the HiRISE camera, the story highlights the HiWish program, in which members of the public can suggest places on Mars to be photographed next. It's an incredible tale of citizen science that allows space enthusiasts like you to influence the data collected by this orbiting martian spacecraft more than 30 million miles (50 million km) away.

One thing is certain: Life or no life, Mars holds powerful lessons.

McEwen is a planetary scientist at the University of Arizona's Lunar and Planetary Laboratory in Tucson and director of the Planetary Image Research Laboratory. He is principal investigator of the HiRISE instrument, and he has a long history of experience with spacecraft missions. He is also a co-investigator of the Lunar Reconnaissance Orbiter Camera team.

Under the leadership of McEwen and others, we continue to investigate the Red Planet. Although very different, it is the most Earth-like place in our solar system, and many feel it would be adaptable for visiting or colonizing in the future. Two scientific rovers are now operating on Mars: Curiosity and Opportunity. And six orbiters are still circling the planet: Mars Reconnaissance Orbiter, Mars Odyssey, Mars Express, Mars Orbiter Mission, MAVEN, and the Trace Gas Orbiter.

Will we find evidence of life, past or present, on Mars? The coming years may finally answer that question. One thing is certain: Life or no life, Mars holds powerful lessons about the changing climate conditions of a planet throughout history and may offer warnings for the future Earth.

Yours truly,

David J. Eicher
Editor

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ASTRO**LETTERS**

Pluto appreciation

When I received the May 2018 issue, I went straight to the article "An organically grown planet definition" by Dr. Runyon and Dr. Stern. I want to thank them both for such a refreshing perspective. We really should be teaching everyone, students and adults alike, "the types and subtypes of planets and how the solar system is naturally organized outward from the Sun, using a handful of planets as examples."

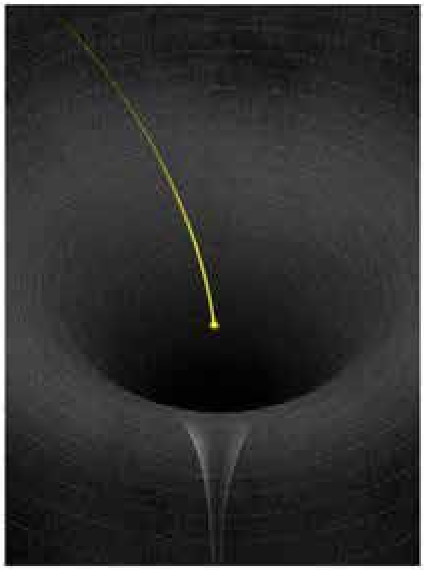
While I wish I had the creative understanding to have arrived at this conclusion myself, that's no matter because it's clearly the right perspective for everyone to have. May we all appreciate the beauty of our solar system, and all types of planets everywhere, because of it!
— **Mike VanVooren,** Ballwin, MO

Squashing conspiracies

I just couldn't read Bob Berman's article "Apathy Now!" from the May 2018 issue without responding. I'm as concerned as you are about the rise of the "conspiracy theory" culture. I'm in my 70s, and I taught science for years. Without any control of what is taught in science classes, credibility is lost. Previously, there was oversight by the government regarding what children were taught in school. Now, science can be taught with computer programs or by individuals who want to promote an agenda — one that directly conflicts with what real science strives to achieve.

We must face the prospect that fantasy is more exciting than science. Watching men and women with super skills save humanity beats a film where humans have to work really hard to reverse the effects of squandering Earth's finite resources. I hope that the article sheds some light on the subject, and that people like Bob keep fighting for science. — **Herb Hoyack,** Shutesbury, MA

We welcome your comments at Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; or email to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*



Illustrating a legend

I wanted to share this personal tribute illustration I did after hearing the news about Stephen Hawking's death. I wish you all the best. — **Brian Stauffer,** Novato, CA

Challenge accepted

To Mr. O'Meara: As a longtime *Astronomy* magazine reader, I have to say that I always enjoy the contents of each issue. There is always something interesting to read, whether it's about new discoveries, upcoming events, or observing tips. Your column in the April 2018 issue, "See the daytime lunar crescent," was very intriguing. I have seen the Full Moon in the daytime, as well as the quarters, but a crescent? I had never noticed, much less tried to see it. I live in Toronto, so light pollution is rampant. However, the daytime sky is pretty much the same as it would be in the country, so I thought to give your suggestion a try.

I had the day off March 19 and was greeted with a mostly clear sky. Checking Stellarium, I saw that the Moon would be almost 40° east of the Sun, a little over 47° high, and 5.6 percent illuminated. I went out at 1:30 P.M. to take a look. It was really hard to find! I noticed what looked to be a crescent, but it could have been a random cloud, too. I grabbed my binoculars and took a look. Yes, that was it!

Trying to make out some detail was difficult, as I'm sure you can imagine. Using my Celestron C80-HD telescope on a CG-4 mount, I found the crescent again, and I could make out what looked to be a few craters on the edge. I took 18 pictures before the crescent started to move out of view, into the branches of our tree. That had to be one of the best days off I've had in a long time, thanks to your article. I enjoy a challenge, and finding a 5.6-percent-illuminated crescent Moon certainly fit the bill. — **Mark Schell,** Toronto

Scientific vs. artistic expression

I just wanted say thank you to Jeff Hester for your article "A murmuration of starlings" in the July 2018 issue. Absolutely fascinating. A simple scientific explanation for a puzzling phenomenon. I always first turn to Jeff's article when opening a new issue of *Astronomy* magazine.

One other comment: In AstroNews of the same issue, it was mentioned that about 70,000 years ago, Scholz's star came within one light-year of the Sun. Assuming it has about the same luminosity as Proxima Centauri, an easy calculation shows that its apparent magnitude would have been 7.99, yet the picture shows an early human looking up in wonderment at a bright red star. Of course it would have been invisible, but nevertheless, I think this is a good example of where artistic license is a positive.
— **Robert Douglas,** Mill Valley, CA

Krypton's cryptic composition

After reading the article "What's in a comet?" in the May issue's AstroNews, I was instantly amused and reminded of the old Superman movie where Richard Pryor studies a deep-space chunk of the planet Krypton, but its composition has an "unknown." Hopefully the Rosetta team's result of 2.4 percent "Other" for Comet 67P is known, but the result is just limited by the column inches of your magazine.
— **Vince Fukes,** Melbourne, Australia

Correction

The "Seeking the unknown in cosmic data" article that begins on p. 30 of the May 2018 issue incorrectly states that physicist Karl Jansky accidentally discovered X-rays emanating from the center of the Milky Way. What he actually discovered was that the Milky Way is emitting radio waves.

QG QUANTUM GRAVITY

EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH . . .

HOT BYTES >>

TRENDING TO THE TOP

BACK TO IT
On May 20, NASA's Curiosity rover successfully drilled its first hole since 2016, using a new technique to circumvent damaged equipment.

NEW SOURCES
The Laser Interferometer Space Antenna, launching in the 2030s, should detect dozens of binary compact objects emitting gravitational waves in globular clusters.

FIRST FLIGHT
NASA will send the Mars Helicopter to the Red Planet with the Mars 2020 rover to test the feasibility of future martian drones.

GEMINI OBSERVATORY/AURA/NSF; TOP FROM LEFT: NASA/JPL-CALTECH/MSSS; NASA/ESA; NASA/JPL-CALTECH

SNAPSHOT

LAVA LAMP

Hawaiian volcano shines at night.

The Hawaiian islands' youngest and most active volcano, Kīlauea, began a surge of activity in May. Located on the southeastern shore of the Big Island, the volcano has since destroyed hundreds of homes.

A cloud-monitoring camera situated at the Gemini North 8-meter telescope atop Mauna Kea, more than 30 miles (50 kilometers) away from Kīlauea, captured light from the eruption May 21–22, as several fissures spewed lava and molten rock that flowed into the sea.

In this image, taken from a longer time-lapse video, the bright glow of the volcano is visible above a sea of clouds and against a backdrop of stars. To the volcano's left, the dimmer yellow glow comes from lights in the town of Hilo. The foreground landscape appears bright, thanks to illumination from the Moon.

Gemini's cloud-monitoring camera is a single-lens reflex camera outfitted with a wide-angle lens, with its infrared-blocking filter removed. Telescope operators use it to monitor large-scale weather conditions at the telescope's elevation (about 13,800 feet [4,200 meters]) to determine whether the sky is clear enough for observing. — **Alison Klesman**

ASTRO**NEWS** **PINT-SIZED.** Researchers have shrunk an entire chemistry lab to the size of a toaster, creating the Mars Organic Molecule Analyzer (MOMA), a key instrument on the planned ExoMars Rover. MOMA will analyze martian soil samples to search for signs of life.

THE FIRST INTERSTELLAR IMMIGRANT

HIDE AND SEEK. Although the backward-orbiting asteroid 2015 BZ_{509} initially came from another star system, it has since been (poorly) hiding out in Jupiter's orbit. NASA/JPL

Less than a year ago, astronomers discovered 'Oumuamua, the first object from another solar system ever seen passing through our own. Now, a new study published May 21 in the *Monthly Notices of the Royal Astronomical Society: Letters* announces the discovery of the first known interstellar object to have taken up permanent residence around the Sun.

Astronomers discovered the asteroid, which has the catchy name 2015 BZ_{509} (Bee-Zed for short), in 2015 using the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS). The discoverers noticed Bee-Zed had a very peculiar yet stable orbit — it shares a nearly perfect 1-to-1 resonance with Jupiter but travels in the opposite direction — but they could not explain its retrograde motion.

"How the asteroid came to move in this way while sharing Jupiter's orbit has until now been a mystery," said Fathi Namouni, the current study's lead author, in a press release. "If 2015 BZ_{509} were a native of our system, it should have had the same original direction as all of the other planets and asteroids, inherited from the cloud of gas and dust that formed them."

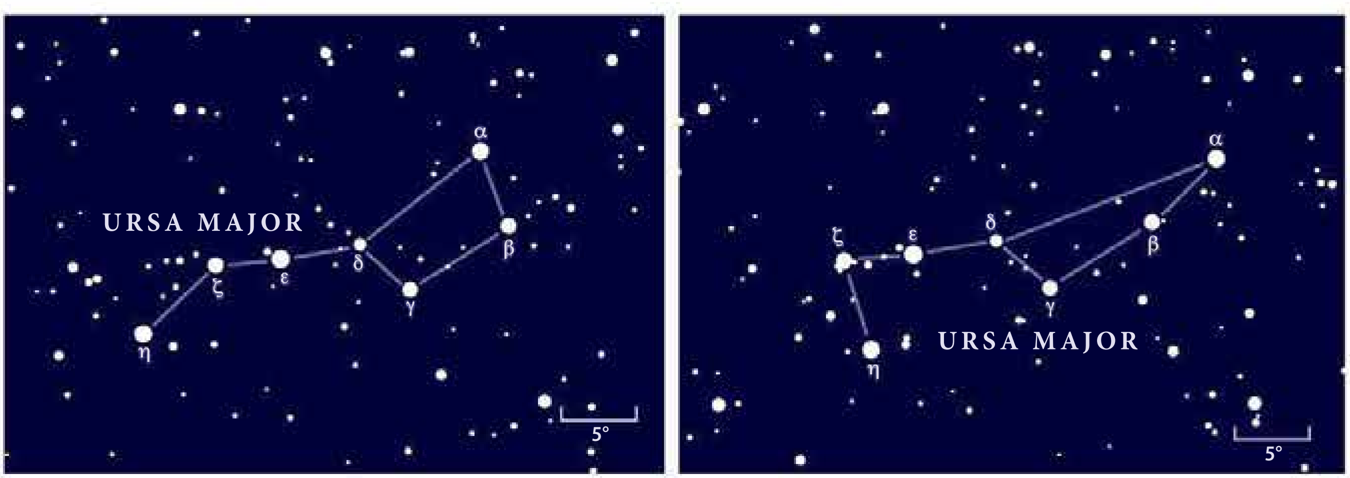
The key insight of the new study comes from simulations that rewound Bee-Zed's motion back 4.5 billion years, to an era when the planets were just finishing forming around the Sun. The researchers showed that the asteroid has always moved in its current, perfectly choreographed orbit that nearly mirrors Jupiter. Therefore, Bee-Zed could not have formed from the co-orbiting disk of debris that surrounded the Sun during its planet-forming phase.

So, if it is not from this solar system, the researchers argue, then Bee-Zed must be from another star system, one that likely formed in the same stellar nursery as the Sun. "Asteroid immigration from other star systems occurs because the Sun initially formed in a tightly packed star cluster, where every star had its own system of planets and asteroids," said team member Helena Morais. "The close proximity of the stars, aided by the gravitational forces of the planets, helps these systems attract, remove, and capture asteroids from one another."

One of the most tantalizing offshoots of this new discovery is the potential for future research to investigate how the Sun is similar to — and more importantly, different from — its ancient siblings. For example, astronomers could dissect the composition of Bee-Zed (through spectroscopic analysis, or even a sample-return mission) to learn how it is chemically distinct from objects forged within our own solar system.

Furthermore, if astronomers can determine exactly which star system the asteroid initially came from, they may be able to learn how the Sun and Bee-Zed's host star interacted in the distant past. This information would teach us a great deal about the Sun's early path to independence, helping us piece together our own cosmic origin story. **— Jake Parks**

THE BIG DIPPER TRANSFORMED



BEAR NECESSITIES. The brightest stars in the constellation Ursa Major the Great Bear form a distinctive asterism called the Big Dipper. But the stars won't always be able to hold water. As they orbit the center of the Milky Way, these suns slowly change position in our sky. Although they resemble a familiar kitchen utensil today (left), the group will be unrecognizable in 100,000 years (right). **— Richard Talcott**

FAST FACT

Five Big Dipper members — Beta (β), Gamma (γ), Delta (δ), Epsilon (ε), and Zeta (ζ) Ursae Majoris — belong to the Ursa Major Moving Group and remain largely aligned.

IN THE DARK. Astrophysical simulations show that early galaxies could have formed if dark energy were 50 times stronger than observed — but they would be 10 times denser, leading to many more observed supernovae.

Ideas about star formation are challenged

The current picture of star formation is this: Within a dense cloud of gas and dust, perturbations cause localized areas to fragment into "cores." These cores further fragment and collapse; when a region in the core reaches the conditions required for fusion, a star is born.

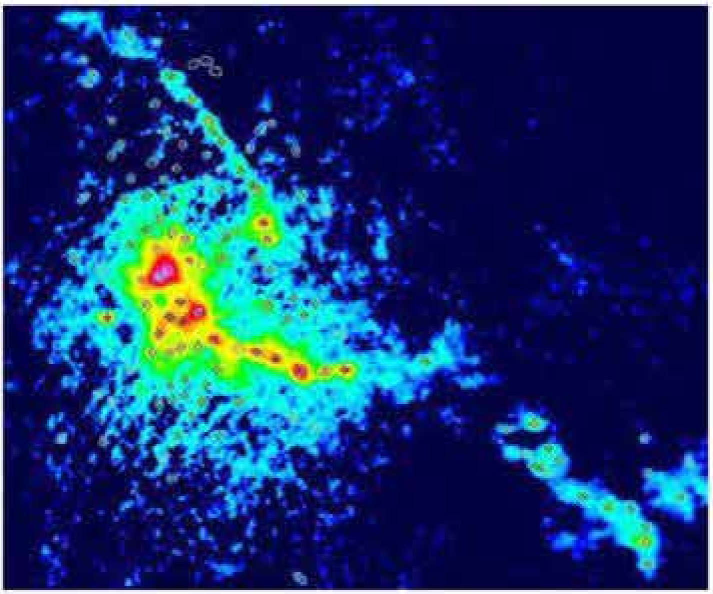
Based on data from nearby star-forming regions, astronomers have long believed that the masses of the stars produced depend on the masses of the cores that develop. And in these nearby regions, cores and stars occur in a consistent pattern: Stars with masses similar to our Sun's are common, but very high- and low-mass stars are rare.

Astronomers had assumed this pattern of mass distribution occurred throughout our galaxy, in clouds of both high and low density. But new observations with the Atacama Large Millimeter/submillimeter Array of the star-forming region W43-MM1 — which, at 18,000 light-years away, lies farther than previously studied areas — are challenging that belief. The results were published April 30 in *Nature Astronomy*.

Why the difference? The molecular clouds in which star formation has been studied in the past are preferentially close to the Sun. That makes them easy to study, but these nearby regions all happen to be less dense than the majority of molecular clouds spread throughout the Milky Way. W43-MM1's density is representative of the denser, more widespread star-forming regions in our galaxy. And within W43-MM1, many more massive cores than expected are present, while fewer smaller cores are found. This suggests the distribution of star masses throughout our galaxy — and others — may not be universal, as astronomers had thought.

"These findings were a complete surprise and call into question the intricate relationship between the masses of star-forming cores and the masses of the stars themselves, which has long been assumed," said study co-author Kenneth Marsh of Cardiff University in a press release.

The team plans to study 15 more regions, all similar to W43-MM1, to determine the significance of the finding. "As a consequence, the community may need to revisit its calculations regarding the complex processes that dictate how stars are born. The evolution of a core into a star involves many different physical interactions, and the results of studies such as this should help us better understand how it all happens," Marsh said. — **A.K.**



ESO/ALMA/F. MOTTE/T. NONY/F. LOUVET/*NATURE ASTRONOMY*

NEW PERSPECTIVE. The star-forming region W43-MM1 is typical of the clouds that form stars throughout the Milky Way. It is also much farther — 18,000 light-years — than any previously observed star-forming clouds, and it indicates that nearby regions of star formation have thus far only shown astronomers part of the picture.

An ant armed with a laser

LIGHT SHOW. A rare double-star system is lurking in the vibrant Ant Nebula, new research suggests. Observations from the European Space Agency's Herschel Space Observatory showed peculiar infrared laser emissions beaming from the nebula's central core, which contains a white dwarf — the remnant of a Sun-like star. To give off this emission, the white dwarf must be closely surrounded by extremely dense gas. However, dying stars usually expel all their dust and gas, leaving an empty expanse nearby. Upon closer investigation, researchers found gas orbiting the dead star in a dense, edge-on disk that can only be explained by the presence of a binary companion. The gravitational field from the companion star deflects gas that would have otherwise shot into space back toward the white dwarf, creating the dusty disk that enables the unique infrared laser emission to occur. — **Amber Jorgenson**

NASA, ESA, AND THE HUBBLE HERITAGE TEAM (STSCI/AURA)

QUICK TAKES

STEADY STATE
Based on models of the two most recent near-reversals of Earth's magnetic field, researchers have determined the field is unlikely to reverse anytime soon.

•

SELF-ASSEMBLY
NASA's Innovative Advanced Concepts Program has greenlit a proposal for a 100-foot-wide modular space telescope that will assemble itself.

•

ZOOMING IN
Astronomers recently observed a pulsar in unprecedented detail, spotting from a distance of 6,500 light-years two regions of radiation just 12 miles (20 kilometers) apart.

•

AMATEUR ASSISTANCE
An amateur astronomer used inexpensive and readily available equipment to collect data identifying a new exoplanet.

•

SPACE INVADER
One of the Milky Way's fastest-moving stars actually hails from another galaxy: the Large Magellanic Cloud.

•

FEED ME
A newly discovered black hole is devouring about a Sun's worth of mass every two days, making it the fastest growing black hole ever found.

•

EARLY START
Astronomers detected oxygen in a galaxy 13.3 billion light-years away, suggesting the first stars began forming a mere 250 million years after the Big Bang.

•

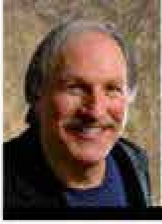
ANOTHER LOOK
Re-examination of data collected by NASA's Galileo spacecraft in 1997 indicates Jupiter's moon Europa may be venting subsurface water through its icy shell.

•

SIGNS OF LIFE
To help in the hunt for alien life, researchers are developing the first framework for tracking seasonal changes related to biological activity in exoplanetary atmospheres.

•

POWER UP
Researchers have successfully demonstrated that a new nuclear fission system can supply power for long-duration manned missions to Mars and beyond. — **J.P.**



STRANGE**UNIVERSE**

BY BOB BERMAN

Searching for obscurity

What makes us look up?

During the next three months, Uranus shines at an unusual magnitude 5.7. If you're in a city, that's still too faint for the unaided eye. But here in my isolated hometown of Willow, New York, population 156, Uranus' rare brightness provokes tail-wagging excitement.

If you can visit rural friends between now and Thanksgiving, you, too, can see Uranus with no optical aid. I hope that this past spring you already observed the asteroid Vesta with your naked eye, since it reached an easy magnitude of 5.5. And while you're in the country, count the Pleiades. Six are obvious, but from dark locales, 11 are not difficult to find if you have good eyesight.

Who would get excited about such dim, barely there objects?

We do.

In truly unpolluted places, the dimmest test target is probably the Triangulum Galaxy (M33). Until I spotted it myself from Organ Pipe Cactus National Monument in southern Arizona, I doubted it was even possible. Then two autumns ago, I saw it from my own backyard. M33 is surprisingly big and perfectly round. But man, it's faint. It's part of a parade of dim but very cool targets.

This year Sirius A and B are separated by about 10", letting backyard telescopes finally see the Dog Star's famous companion, "The Pup." Glimpsing this white dwarf is hard because it's 25,000 times dimmer than the primary. For the next decade, they are maximally separated in their 50-year orbit, spread apart by the same distance as the Sun from Uranus. I've enjoyed the much easier white dwarf 40 Eridanus B. But seeing the Earth-sized Pup, the most famous white dwarf, delivers a thrill. It's the same thrill as seeing Uranus naked-eye. Or counting 11 Pleiads.

Why? Is it the challenge? The test of night vision? You hardly need astronomy for that. After nightfall, many homes have scurrying cockroaches. Residents could theoretically tiptoe into a dark kitchen to assess how many they can count. Taking such an inventory would provide an easy appraisal of nocturnal vision acuity. Yet amateur astronomers probably prefer to count stars in the Pleiades, even though it inconveniently requires stepping into chilly air. This suggests we're motivated by something other than testing eyesight.

A more basic assessment to see whether real darkness even exists in your environment involves merely checking for the presence of color. Human vision uses two separate physiological processes that switch on and off beyond our control. The first, which yields sharp, colorful images whenever the environment is bright, is called photopic vision. The second, which produces less distinct grayscale images in low-light conditions, is scotopic vision.

Who would get excited about such dim, barely there objects?

Can you see Uranus without a telescope? If you live in — or travel to — a rural area this fall, the answer may be yes. Amateur astronomers revel in challenges like spotting the magnitude 5.7 disk of our solar system's seventh planet. NASA/JPL-CALTECH/KEVIN M. GILL

At any given moment, it's easy to tell which is operating.

Observing any galaxy through a telescope automatically employs scotopic vision. Its maximum acuity is 20/200. That's legally blind. Let's repeat: Observing a galaxy through a telescope renders you legally blind. It's no wonder that at the eyepiece, you cannot perceive the sharp galactic detail displayed in this magazine's photographs. And since scotopic is grayscale, no one's ever directly seen the Whirlpool's campfire-yellow core or its cobalt spiral arms.

A luminosity below 0.7 lambert is where our vision switches to scotopic and thus becomes colorless. (A lambert is defined as the brightness of a light source that emits 1 lumen per square centimeter.) For comparison, the average flat-panel TV has a brightness of 100 lamberts. So the next time you're observing from your backyard, check to see if there's any color around you. If the ambient light pollution is sufficient to make grass look green and show your home's exterior color, you automatically know your photopic vision is operating — which also means no Uranus. It's simply not dark enough.

An easy alternate demo of your personal scotopic/photopic boundary involves checking star tints. There are no green stars, but the pastel blue of Rigel, Spica, and Sirius, or the orange of Aldebaran and Betelgeuse, are obvious because these are bright enough to reliably provoke photopic vision. But now look at the Great Square of Pegasus, nicely up at midnight. Scheat, upper right, is reddish, but at 2nd magnitude may or may not stimulate a photopic response. Markab, lower left, is blue, but at 3rd magnitude almost definitely won't show its color. Now boost these stars to 0 magnitude by using binoculars. Bingo. Their colors dramatically pop. Binoculars let you determine where your scotopic vision kicks in.

Travel to where there's no doubt. Drive a few hours until you reach "nowhere." In early autumn, the reward is the year's best faint, intricate celestial detail, such as the countless Dali-esque dust lanes in the Cygnus Milky Way. Such grayscale attractions are endless because the faint universe is a bottomless realm.

And if this majestic obscurity belongs to any group of people, it belongs to us.

Join me and Pulse of the Planet*'s Jim Metzner in my new podcast,* Astounding Universe*, at* **http://astoundinguniverse.com.**

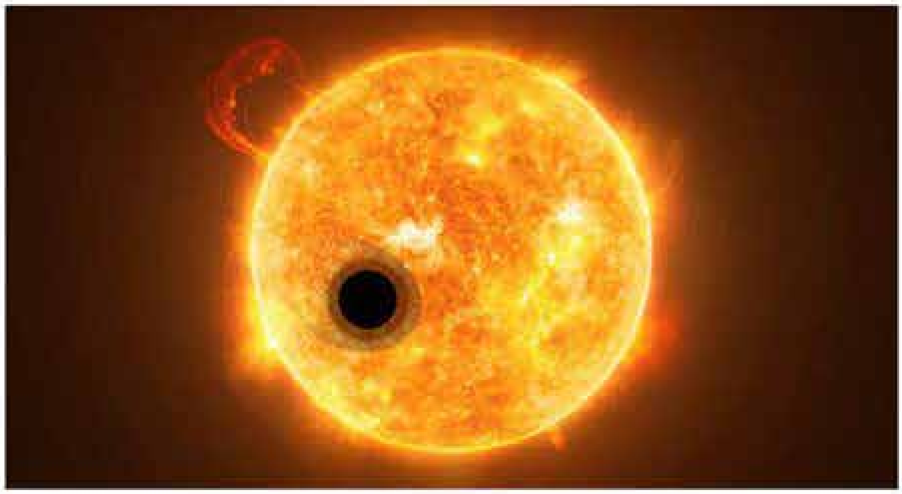
BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman.**

ASTRO**NEWS** **TEAM UP.** Although rivals for almost 20 years, the Giant Magellan Telescope and the Thirty Meter Telescope are now working together to secure much-needed funding from the National Science Foundation.

Helium found in alien atmosphere

An international team of researchers made the first-ever detection of helium in the air of a planet outside our solar system, according to a study published May 2 in the journal *Nature*. The target, the exoplanet WASP-107b, showed a helium signal so strong that researchers think the planet's upper atmosphere may stretch thousands of miles into space, where strong stellar winds likely create an extended cometlike tail of gas around the exoplanet.

To carry out their investigation of WASP-107b, the researchers tried a novel technique to probe the exoplanet, using the Wide Field Camera 3 on the Hubble Space Telescope to view infrared light passing through the planet's upper atmosphere. By analyzing the light's spectrum, the researchers then were able to decode the elemental composition of the planet's air, ultimately finding a great deal of helium in an excited state.

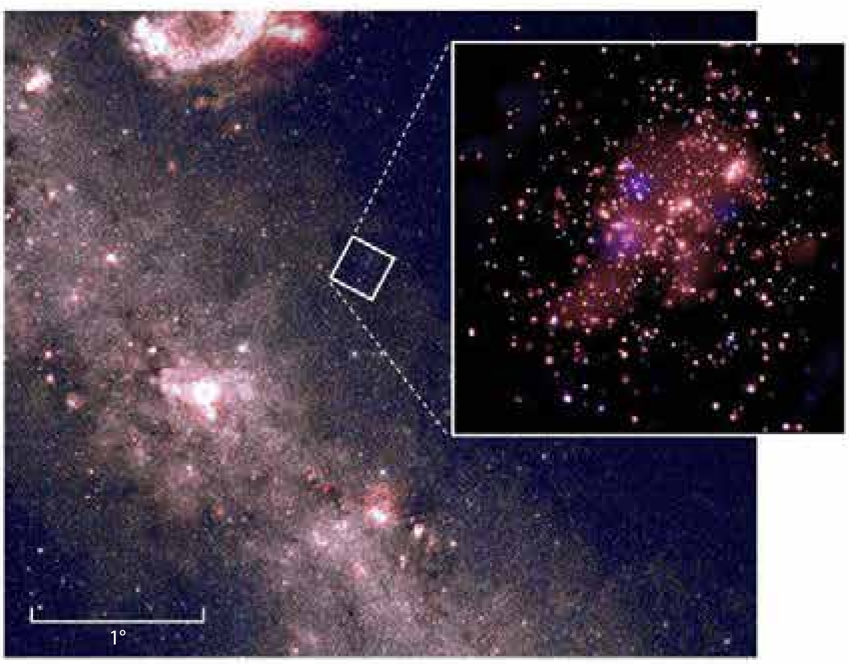


HOT AIR. WASP-107b, which was initially discovered last year, is a gas giant roughly the size of Jupiter, but it is only 12 percent as massive, making it one of the lowest-density planets known. It is also about eight times closer to its host star than Mercury is to the Sun, making it one of the hottest planets (932° Fahrenheit, or 500° Celsius) yet found. ESA/HUBBLE/NASA/M. KORNMESSER

"The strong signal from helium we measured demonstrates a new technique to study upper layers of exoplanet atmospheres in a wider range of planets," said lead author Jessica Spake, of the University of Exeter, in a press release. "Current methods, which use ultraviolet light, are limited to the closest exoplanets. We know there is helium in the Earth's upper atmosphere, and this new technique may help us to detect atmospheres around Earth-sized exoplanets — which is very difficult with current technology."

Although future projects could use telescopes here on Earth to study exoplanet atmospheres, the new technique may be even more valuable for future space-based observatories. "We hope to use this technique with the upcoming James Webb Space Telescope, for example, to learn what kind of planets have large envelopes of hydrogen and helium, and how long planets can hold on to their atmospheres," said Spake. "By measuring infrared light, we can see further out into space than if we were using ultraviolet light." — **J.P.**

Chandra separates old stars from young

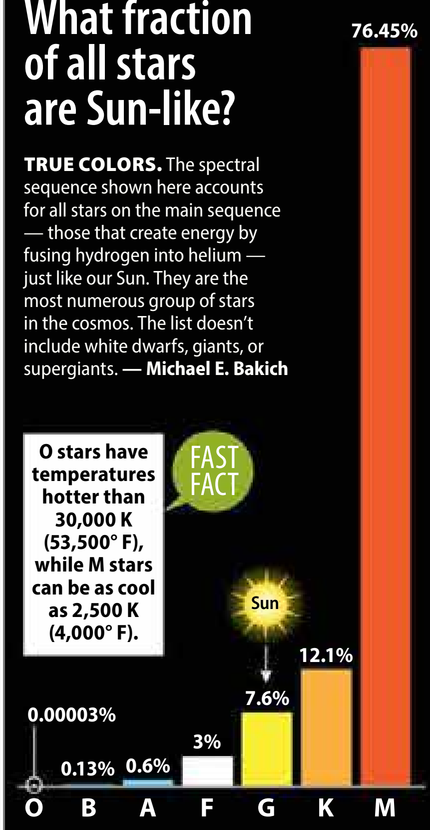


X-RAY: NASA/CXC/VALPARAISO UNIVERSITY/M. KUHN ET AL; IR: NASA/JPL/WISE

AGE GAP. NASA's Chandra X-ray Observatory captured a close-up photo of NGC 6231, a star cluster that astronomers estimate houses between 5,700 and 7,500 young Sun-like stars. Because of their location in the disk of the Milky Way, these stars are difficult to pick out visually among the older stars scattered in front of and behind them. But strong magnetic activity associated with young stars heats their outer atmospheres to tens of millions of degrees, causing them to emit X-rays and allowing Chandra to spot them. The cluster has just reached the point where it no longer forms stars, giving researchers a chance to study how star clusters evolve at this pivotal stage. Will the stars in NGC 6231 disperse, like the cluster our Sun likely formed in, or will they stay in their close-knit group, bound by gravity? Only time will tell. — **A.J.**

What fraction of all stars are Sun-like?

TRUE COLORS. The spectral sequence shown here accounts for all stars on the main sequence — those that create energy by fusing hydrogen into helium — just like our Sun. They are the most numerous group of stars in the cosmos. The list doesn't include white dwarfs, giants, or supergiants. — **Michael E. Bakich**



ASTRONOMY: ROEN KELLY

MOVING OUT. Astronomers determined Kuiper Belt object 2004 EW_{95} is a carbon-rich asteroid that likely formed in the asteroid belt before it was ejected from the inner solar system by the early outward migration of the gas giants.

NASA successfully launches Mars InSight, GRACE-FO missions

Two space science missions successfully launched from Vandenberg Air Force Base in California in May.

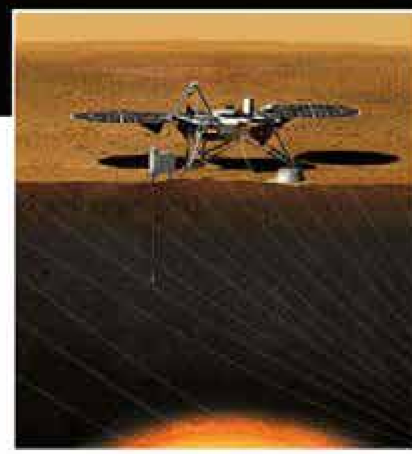
At 4:05 A.M. PDT May 5, NASA's Mars InSight (short for Interior Exploration using Seismic Investigations, Geodesy and Heat Transport), riding atop an Atlas V-401 rocket, became the first interplanetary mission launched from the West Coast.

On May 23, NASA reported that InSight had successfully begun steering toward the Red Planet. Course corrections are needed because although the InSight lander was cleaned of all Earth microbes, its Atlas rocket was not. To prevent contamination, the rocket lifts off with a trajectory that avoids Mars, requiring the spacecraft to change its course after separating from the launch platform.

InSight will land November 26 and become the first mission to study the deep interior of the Red Planet with instruments designed to track heat flow, planetary tilt, and even marsquakes. Among other goals, Insight will measure how much Mars' poles wobble as the planet orbits the Sun to determine the composition and state (solid or liquid) of Mars' core.

"InSight will not only teach us about Mars, it will enhance our understanding of formation of other rocky worlds like Earth and the Moon, and thousands of planets around other stars," said Thomas Zurbuchen, associate administrator for NASA's Science Mission Directorate, in a press release.

ARC OF LIGHT. The Atlas V-401 rocket carrying Mars InSight arcs over Los Angeles on its way to the Red Planet on May 5. D. ELLISON



DEEP DIVE. Once on the surface of Mars, InSight will study the planet's interior to determine its current composition and formation history. JPL/NASA

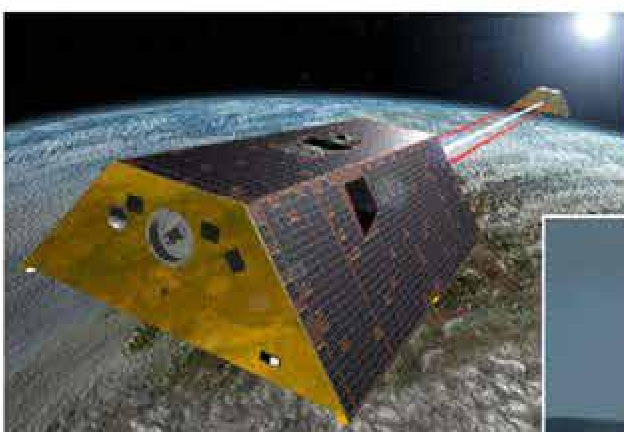
"Scientists have been dreaming about doing seismology on Mars for years," added Bruce Banerdt, the mission's principal investigator at the Jet Propulsion Laboratory.

Trailing InSight on its journey is Mars Cube One, or MarCO, which consists of two CubeSats. They are the first CubeSats to leave Earth's gravitational influence and will demonstrate technology for future interplanetary missions, as well as collect data during InSight's landing to improve future efforts to land in Mars' challenging thin atmosphere.

On May 22, GRACE-FO (Gravity Recovery and Climate Experiment Follow-On), a joint NASA/German Research Centre for Geosciences (GFZ) mission, lifted off at 12:47 P.M. PDT aboard a SpaceX Falcon 9 rocket. The two GRACE-FO satellites will track movement and changes in Earth's mass by tracking precisely the pull of gravity around the planet. As the satellites orbit, they will communicate via microwaves and a laser light, allowing them to monitor their separation from each other. Changes in Earth's gravity field, dictated by the mass passing beneath the satellites, will alter their distance, allowing them to build an ongoing map of the planet's mass, including when, where, and how it shifts.

The "FO" is derived from the fact that it "follows on" the initial GRACE mission, which ended in 2017 after taking gravity measurements for 15 years. GRACE-FO has a planned five-year mission. The spacecraft began relaying test data successfully in June, less than three weeks after launch.

"GRACE-FO will provide unique insights into how our complex planet operates," said Zurbuchen. "Just as important, because the mission monitors many key aspects of the Earth's water cycle, GRACE-FO data will be used throughout the world to improve people's lives — from better predictions of drought impacts to higher-quality information on use and management of water from underground aquifers." — **A.K.**



A MATCHED PAIR. The two satellites that make up GRACE-FO continuously measure their separation with high precision as they pass over Earth. Differences in the planet's gravitational field associated with changes in mass will affect the separation, allowing the satellites to track mass and its motion over time. NASA

GOING UP. The twin spacecraft of GRACE-FO lifted off May 22 from Vandenberg Air Force Base in California, sharing a SpaceX Falcon 9 rocket with several other satellites. NASA/BILL INGALLS

CLEAR SKIES. Astronomers discovered a "hot Saturn" exoplanet, WASP-96b, that is completely free of clouds.

Star-forming cloud is mapped with sound

Our solar system formed from a cloud of gas and dust about 4.5 billion years ago. Now, a team of astronomers from the Australian National University (ANU) and the University of Crete in Greece has imaged in 3D an interstellar cloud in the early stages of doing the same. Their findings were published May 11 in *Science*.

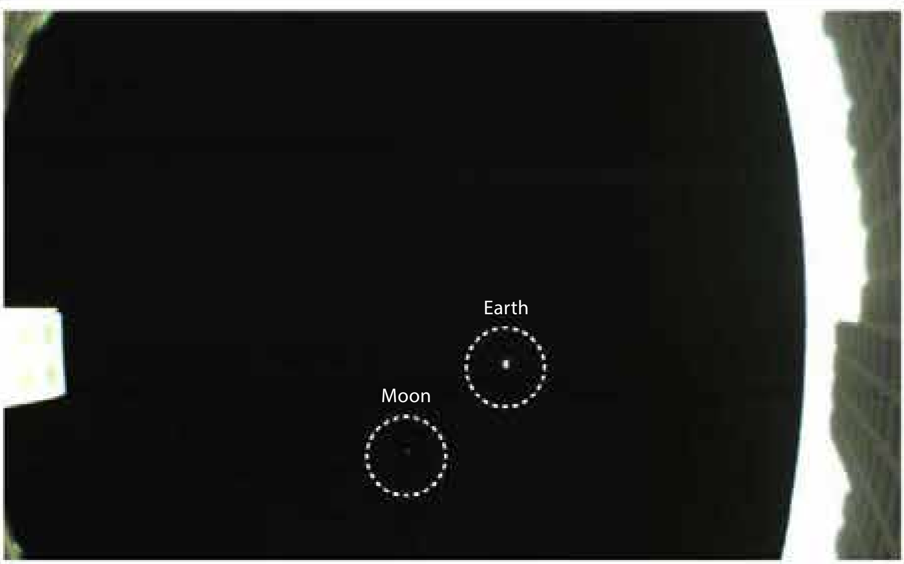
The cloud, called Musca, is 570 light-years from Earth. Though it appears needle-shaped on the sky from our vantage point, the team has determined it is actually a flat, sheet-shaped cloud rather than a long, thin filament.

To map Musca's three-dimensional structure, the team looked to a series of thin, ordered structures called striations, which surround the core of the cloud. These striations result from waves of gas and dust moving through the cloud, which itself shows global oscillation. "This is a cloud in space that is singing to us — all we had to do was listen. It's actually quite awesome," said lead author Aris Tritsis of ANU in a press release.

As the entire cloud vibrates, a unique pattern of striations is produced. The pattern holds within it information about the boundaries of the region that produced it. Working to decode this information, the team modeled several possible cloud shapes and the resulting patterns of striations that occur when the model clouds oscillated at the frequencies observed. They finally arrived at a model that matched the striations observed around Musca: a sheet about 27 light-years in length, 20 light-years in width, and half a light-year thick.

"We were able to reconstruct the 3D structure of a gas cloud in its very early stages of making new stars and planets, which will ultimately take millions of years to form," said Tritsis. "Knowledge of the 3D shape of clouds will greatly improve our understanding of these nurseries of stars and the birth of our own solar system." — **A.K.**

DARK STREAK. The Musca molecular cloud appears as a dark slash against the starry background at the bottom of this image. Although it appears filament-like due to projection effects, astronomers recently mapped the cloud's 3D structure and discovered it is a thin, flat sheet seen edge-on from Earth. NASKIES AT EN.WIKIPEDIA



NASA/JPL-CALTECH

Earth caught on CubeSat camera

LOOKING BACK. Voyager 1's "Pale Blue Dot" image of Earth was taken in 1990 from more than 4 billion miles (6 billion kilometers) away. Since then, several spacecraft have taken images of Earth from other planets. This newest planetary portrait was taken May 9 with a fisheye camera on MarCO-B, one of the two tiny CubeSats accompanying Mars InSight on its journey to the Red Planet. The photo was taken just one day after the CubeSats set a distance record by traveling more than 600,000 miles (1 million km) from Earth. If it seems that Earth and the Moon haven't been ideally framed in the shot, it's because they were a bonus — the image was actually taken to ensure the CubeSat's high-gain antenna had unfolded as expected. — **A.K.**

FOR**YOUR**CONSIDERATION

BY JEFF HESTER

Making sausage

It's not personal. It's science.

POJOSLAW/DREAMSTIME

Magazines like *Astronomy* do a wonderful job making neat science accessible to the public, but that's not always such a great thing. Slick press releases and well-written articles about fun discoveries can make science look easy; it's anything but.

I'm not talking about the difficulty of the subject matter itself, although the chasm between a popular article and the science it describes can be vast. I'm talking about the human experience of doing science, which can be brutal.

Some questions are matters of opinion. Yankees or Red Sox? Asparagus or green beans? Other questions are not. How many protons are in a carbon nucleus? Is the Moon made of green cheese? How did life begin?

There are answers to those questions that depend in absolutely no way, shape, or form on opinion or belief. We can stand on a hilltop and shout at the heavens, but the universe is never going to rearrange itself to suit our notions of how things ought to work.

That's where science comes in.

If you learn nothing else from reading my column, at least learn this: Science is an intellectually violent activity! Scientific knowledge comes from destructively testing ideas. (See my column from November 2015, "Postmodernist airplanes.") A scientist's duty is to logically and honestly use all available evidence to try to tear ideas to shreds. If an idea can survive that gantlet, then it is worth holding onto, at least for now. But if it can't survive, bye-bye. C'est la guerre!

Huh? What do you mean, "tear ideas to shreds?" What do you mean, "opinions and beliefs don't matter?" That's really harsh, man!

Yep, it sure is. But that's how the game is played. Airplanes fly, computers compute, and spacecraft navigate the solar system because when it really matters, those rules work better than any other rules humans have ever come up with.

Even so, living by those rules can suck. We humans often fall deeply in love with ideas and beliefs, present company included. That's especially true when an idea or belief helps bind us to our social group, and it's as true for scientists as it is for anyone else. Our shared values are built around discovering how the world works, and knowing that in a confrontation between opinion and evidence, evidence wins.

"For Your Consideration" invites readers to push aside the decorative curtain of packaged-for-the-public science, step into the kitchen, and see how the sausage is made.

Instead of, "Run it up a flagpole and see who salutes," science is more, "Run it up a flagpole and see if there is anything left after people finish shooting at it." A scientist has to get used to the notion that when you share an idea, people respond by looking for reasons why you're wrong. When they finish, they go back and look some more. Then a new generation comes along with new and better tools, and they have a go at you, too!

Pulling punches is clearly a no-no. If scientists start going easy on ideas just to protect people's feelings, airplanes start falling out of the sky.

I need to be careful with my wording here. It's not that your peers have a go at you, personally. What they have a go at is the idea you love so much. If you want to survive science in one emotional piece, that's an important distinction. It's not personal. It's science! I can't count the number of times I've gone toe-to-toe with someone over a scientific disagreement, only to sit down later and drink a beer with the dear friend I just went 12 bloody rounds with.

This column invites readers to push aside the decorative curtain of packaged-for-the-public science, step into the kitchen, and see how the sausage is made. Sanitizing science or soft-pedaling its implications would defeat the whole purpose.

Things I write about can make some readers uncomfortable, but it's not my intention to be snarky. I write about that stuff because it's important. Intelligent design, for example, is a cause célèbre for groups that want to gut science education nationwide. Climate change is an existential issue facing human civilization. The anti-vaccine movement puts public health at serious risk. It would be irresponsible and frankly unfair to readers to sweep stuff like that under the rug.

All this applies to me, too, by the way. If you disagree with something that I say, show me evidence that falsifies testable predictions, and I'm all ears. But if something I say just gets someone's hackles up, my answer will always be the same: The rules are the rules.

There you have it. Human exploration of the universe and of ourselves continues at an ever-accelerating pace, and what we are learning is as amazingly, mind-blowingly cool as it is profound. But there is no getting around letting the pieces fall where they may. That's not personal. That's science.

Jeff Hester is a keynote speaker, coach, and astrophysicist. Follow his thoughts at **jeff-hester.com.**

BROWSE THE "FOR YOUR CONSIDERATION" ARCHIVE AT **www.Astronomy.com/Hester.**

 WHIRLIGIG. NASA's NICER mission discovered a pulsar and its companion orbiting each other every 38 minutes. The pair has the shortest-known orbital period in their class of pulsar binaries.

X-ray satellite is gone, not forgotten

NASA's Rossi X-ray Timing Explorer (RXTE), which operated from 1996 until 2012, burned up in Earth's atmosphere April 30. Although the satellite has not operated for six years, its data continue to provide astronomers with a valuable and unprecedented look at high-energy objects, such as pulsars and black holes.

"Observing these X-ray phenomena with precise high-resolution timing was RXTE's specialty," said Jean Swank of NASA's Goddard Space Flight Center in a press release. Swank served as the mission's project scientist until 2010. "During RXTE's run, no other observatory could provide these measurements."

Today, "the data remain a treasure-trove for studying compact objects, whether pulsars and stellar-mass black holes in our own galaxy or supermassive black holes in the cores of distant galaxies," said Tod Strohmayer, also of Goddard, who was RXTE's project scientist from 2010 to 2012.

RXTE allowed astronomers to watch the motions of hot gas around black holes, charting the intricacies of the accretion disks of matter that gather to swirl into the black hole like water flowing down a drain. In 1997, RXTE returned the first observational evidence of a phenomenon called frame dragging. By watching the way blobs of hot gas moved very close to the edge of a black hole, astronomers observed how the black hole's immense gravity dragged space-time near the event horizon along with it, just as relativity predicts.

The satellite's successor, the Neutron star Interior Composition Explorer (NICER), is currently installed on the International Space Station, allowing astronomers to continue studying in detail variable X-ray sources such as pulsars, black holes, and extreme stars. — **A.K.**

ON YOUR MARK. In 1995, the Rossi X-ray Timing Explorer was processed for mounting atop a Delta II 7920 rocket prior to its December 30 launch. During its 16-year mission, the satellite helped to unlock the mysteries of black holes and pulsars by observing these fast-changing objects with high precision.

NASA'S KENNEDY SPACE CENTER

CLOUDY WITH A CHANCE OF ...

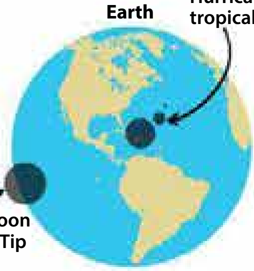
STORMY WEATHER. Storms rage throughout our solar system, from Venus to Neptune. Some would only partially cover the United States, while others could swallow Earth whole. — **A.K.**

Venus

Venus' south pole is covered by a vortex bounded by a "collar" of cold air 1,240 miles (2,000 km) across, roughly half the width of the U.S.

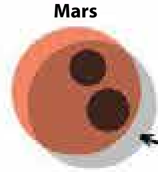
500 miles
1,000 km

Earth



On Earth, hurricanes and tropical storms typically range 100–400 miles (160–640 km) in diameter. The largest storms are about 1,000 miles (1,600 km) across; Super Typhoon Tip stretched 1,380 miles (2,220 km), about half the width of the U.S.

Mars



On Mars, most dust storms are less than 1,200 miles (1,930 km) across, but large storms can cover anywhere from one-third of the planet (1,407 miles [2,260 km]) to rarer globe-spanning dust storms (Mars' diameter is 4,220 miles [6,790 km]) that would stretch halfway across Earth if laid out.

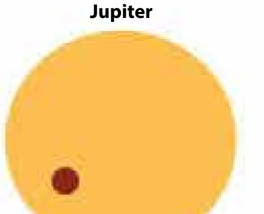
Jupiter

Jupiter's Great Red Spot is 10,250 miles (16,500 km) across. It would cover about 1.3 Earths lined up next to each other.

FAST FACT

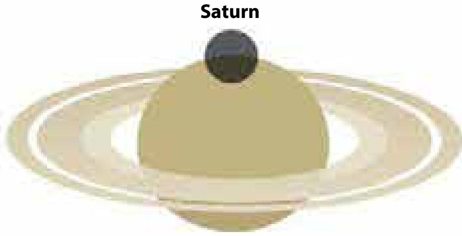
Jupiter's Great Red Spot has persisted for centuries, but Neptune's Great Dark Spots are transient. GDS-89 vanished between 1989 and 1994.

Jupiter



30,000 miles
50,000 km

Saturn

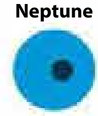


The north polar hexagon of Saturn is about 20,000 miles (32,200 km) wide, the equivalent of 2.5 Earths. Individual vortices within the larger hexagon are 2,200 miles (3,540 km) across, or eight-tenths the length of the U.S.

Uranus

On Uranus, some storms can range about 6,200 miles (10,000 km), nearly the diameter of Earth.

Neptune

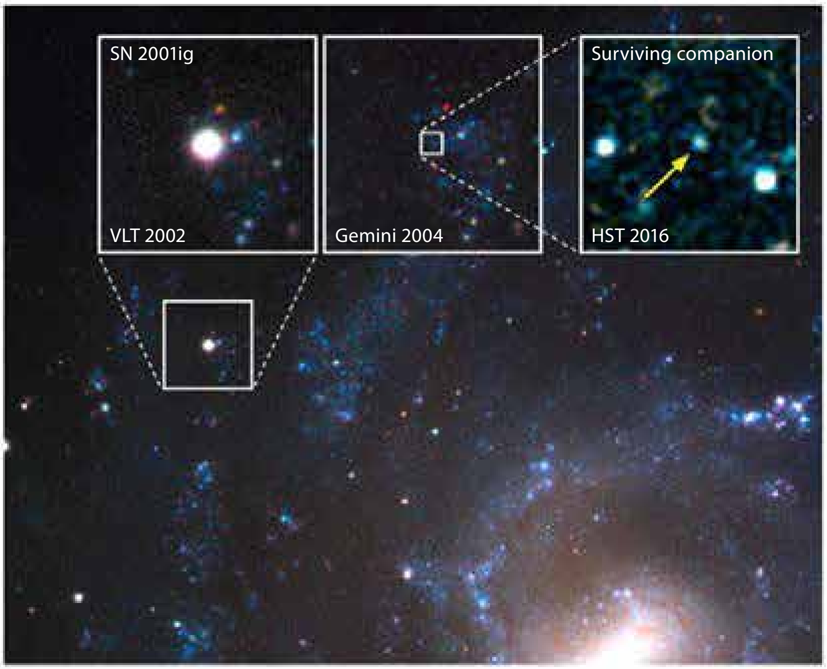


Neptune's Great Dark Spot, also called GDS-89, was imaged with Voyager 2 at 8,100 miles (13,000 km) across, just over the diameter of Earth.

ASTRONOMY: ROEN KELLY

ASTRONEWS

SMOOTH IT OUT. NASA's Magnetospheric Multiscale mission found that Earth's protective magnetic field periodically breaks and reconnects, taming turbulence induced by the solar wind.



STANDING STRONG. This is the first image of a surviving companion to a supernova blast. Thanks to Hubble's high resolution and exquisite ultraviolet sensitivity, astronomers now know that some supernovae have roots in double-star systems. NASA/ESA/S. RYDER (AUSTRALIAN ASTRONOMICAL OBSERVATORY)/O. FOX (STScI)

Hubble spots a supernova survivor

Using NASA's Hubble Space Telescope, astronomers have captured the first-ever photograph of a surviving companion following a supernova.

The image of the companion star, which was seen in the fading afterglow of a supernova that exploded some 40 million light-years away in the galaxy NGC 7424, provides the most compelling evidence yet that some supernovae originate in binary systems.

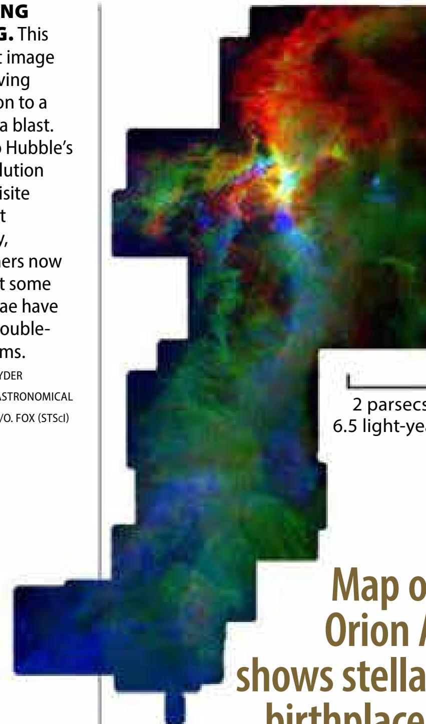
The supernova in question, SN 2001ig, is a Type IIb stripped-envelope supernova. This unusual type occurs when the majority of a massive star's hydrogen is stripped away prior to exploding.

"We know that the majority of massive stars are in binary pairs," said lead author Stuart Ryder, an astronomer at the Australian Astronomical Observatory in Sydney, in a press release. "Many of these binary pairs will interact and transfer gas from one star to the other when their orbits bring them close together."

In the case of SN 2001ig, astronomers believe the companion star siphoned off nearly all the hydrogen from the outer shell of the supernova's progenitor. Since the outer region of a star is extremely efficient at transferring energy from the core outward, the absence of an envelope can lead to an instability that ultimately causes an epic explosion.

Though it may seem surprising that a star so close to a supernova can survive, when you take into account the structure of stars, it makes sense. A star is made of a dense core surrounded by a relatively loosely held shell of hot plasma and gas. When the shock wave from SN 2001ig struck its neighboring star, the companion star's gaseous envelope temporarily deformed, but its core held strong.

With this new image, astronomers have finally proven that at least some stripped-envelope supernovae have companions, but now their goal shifts to determining exactly how many. — **J.P.**



NSF/S. KONG, J. FEDDERSEN, H. ARCE, & CARMA-NRO ORION SURVEY TEAM

Map of Orion A shows stellar birthplaces

EXQUISITE DETAIL. Researchers recently merged data from the Nobeyama Radio Observatory (NRO) telescope and the Combined Array for Research in Millimeter Astronomy (CARMA) to create the most detailed star map of the nearby Orion A molecular cloud to date. Sitting about 1,200 light-years from Earth, this molecular cloud is the closest region to us that is currently birthing high-mass stars. Among its varied star-forming environments, Orion A houses compact star clusters similar to the one astronomers believe our Sun likely formed in. These data from the CARMA-NRO Orion Survey will now allow researchers to study how stars form and evolve, and also assist in predicting the stellar populations of distant galaxies, based on Orion A's behavior. — **A.J.**

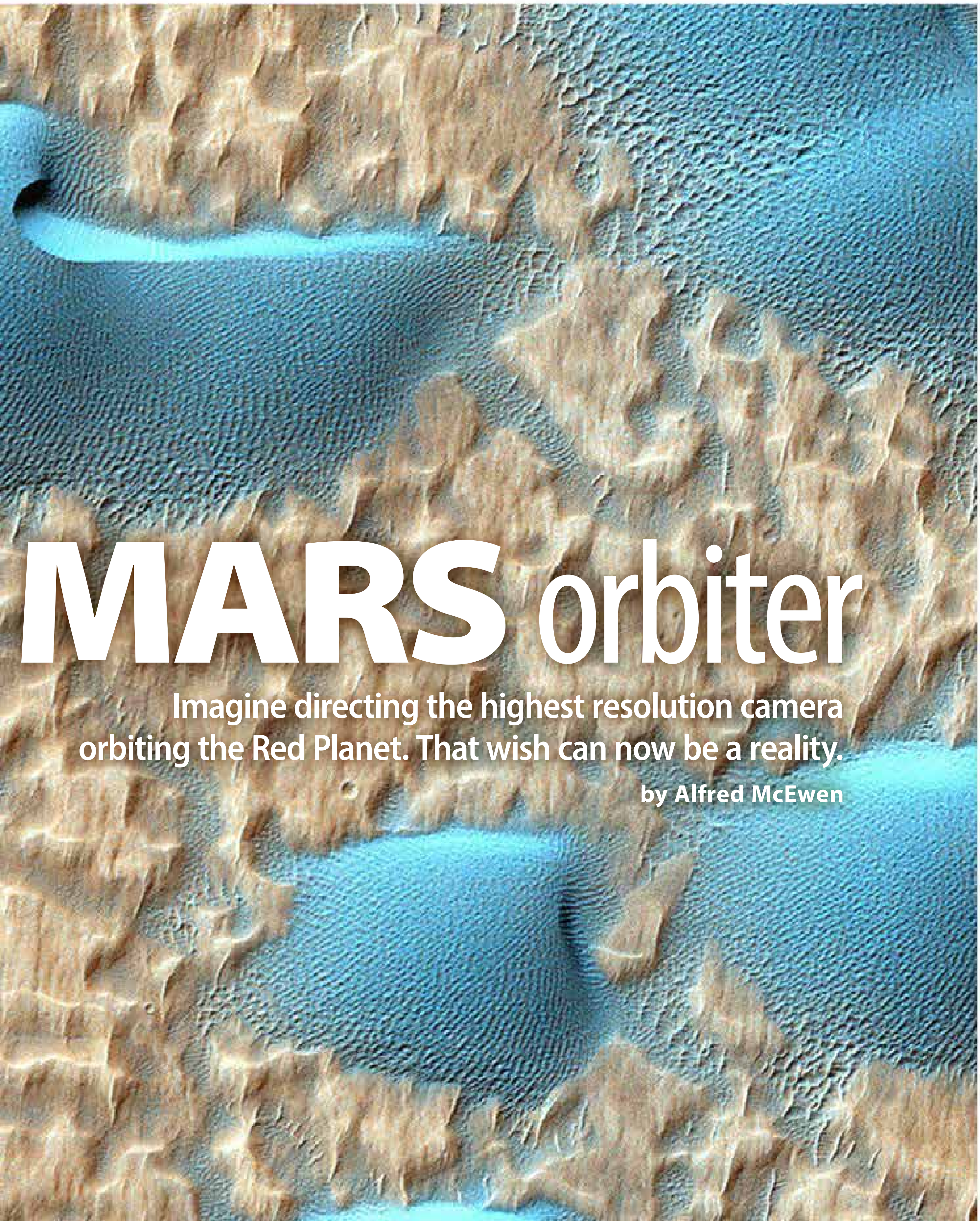
ExoMars returns its first image from orbit

ESA/ROSCOSMOS/CASSIS

NOT SO RED. The ExoMars spacecraft arrived in orbit around the Red Planet in early April. On April 15, its Colour and Stereo Surface Imaging System (CaSSIS) took three images nearly simultaneously, and they were combined to create this stunning final photo, covering 25 miles (40 kilometers) of the rim of Korolev Crater in Mars' northern hemisphere. Ice sweeps out from the crater's edge, shining brightly against the martian surface. ExoMars, a joint endeavour of the European Space Agency and Roscosmos, derives its name from the term *exobiology* and consists of two missions: the Trace Gas Orbiter currently at the Red Planet, and a surface rover set to launch in 2020. — **A.K.**

Take control of a

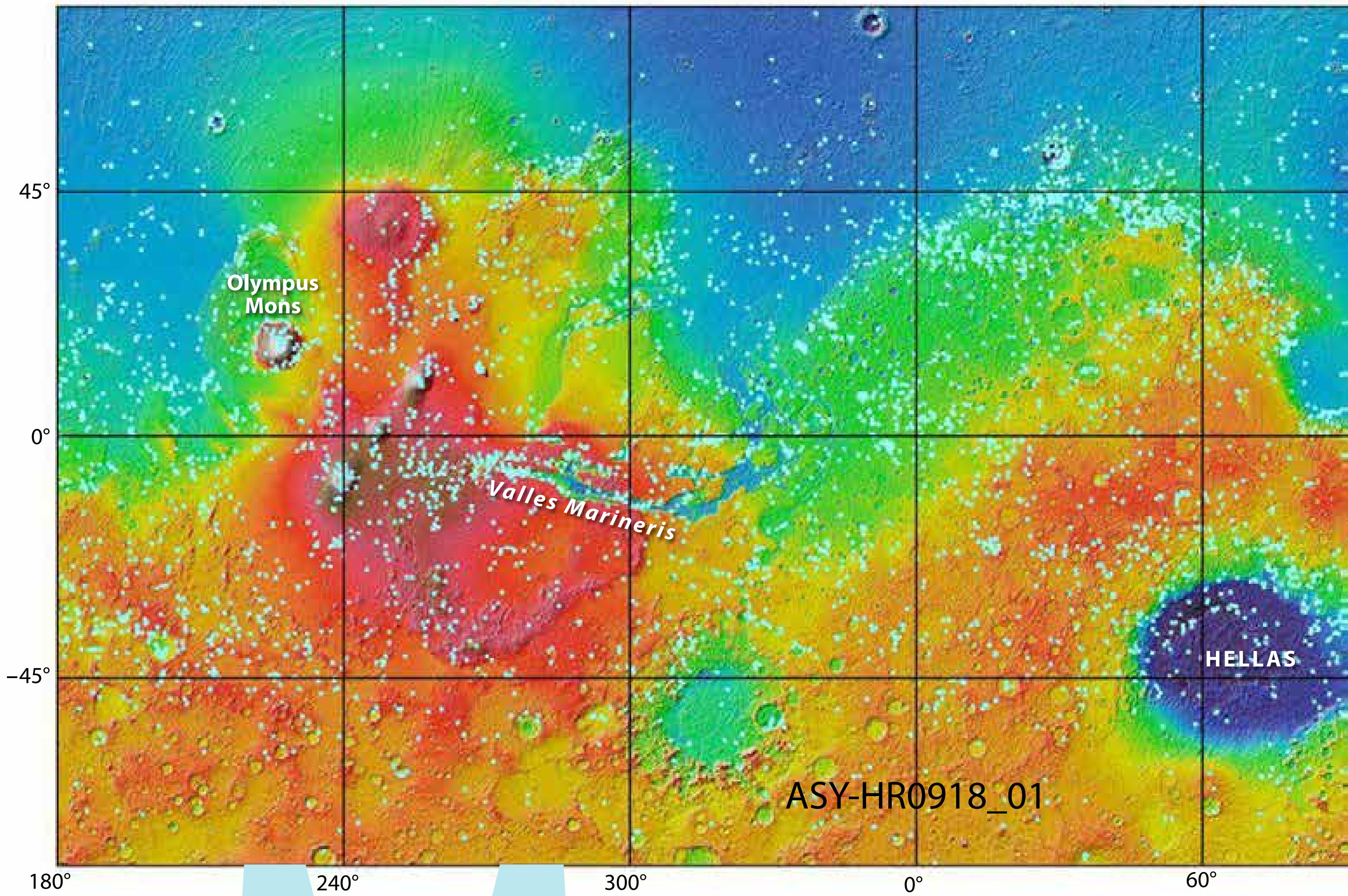
This field of sand dunes rests on the complex, eroded floor of an ancient crater in Noachis Terra. The dunes have gentle slopes to the southwest (lower left) where they face the prevailing wind, and steep slopes on the opposite side. ALL IMAGES: NASA/JPL/UNIVERSITY OF ARIZONA UNLESS OTHERWISE NOTED



MARS orbiter

Imagine directing the highest resolution camera orbiting the Red Planet. That wish can now be a reality.

by Alfred McEwen



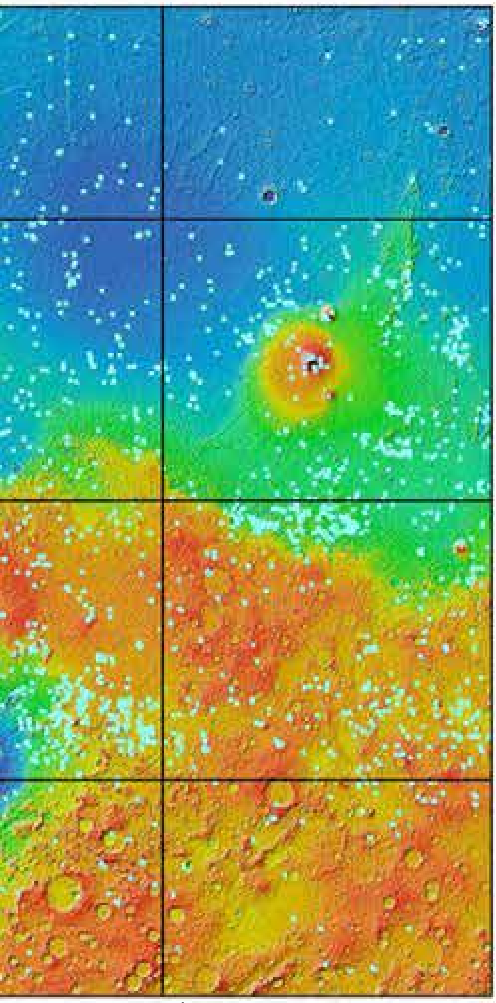
Mars exploration entered a new era in 2006. In March of that year, NASA's Mars Reconnaissance Orbiter (MRO) fired its main engines for 27 minutes, slowing the sophisticated probe enough for the Red Planet's gravity to capture it into a highly elliptical orbit. During the next five months, MRO repeatedly dipped into the martian atmosphere. Friction with air molecules slowed the craft more, gradually modifying its course until it reached its final science orbit, a near-circular path with a lower altitude and shorter period. Now, a dozen years later, MRO has sent more data to Earth than all other interplanetary missions in history combined.

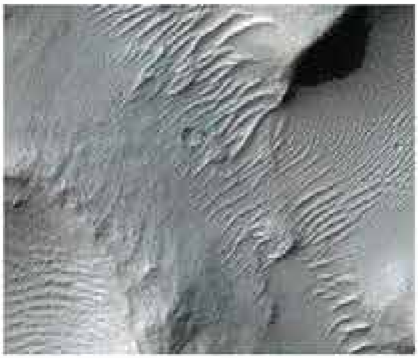
A good chunk of that data comes from the High Resolution Imaging Science Experiment (HiRISE), on which I am the principal investigator. The camera has acquired more than 52,000 high-resolution orbital images of Mars' surface. The photos achieve resolutions as high as 10 inches (25 centimeters) per pixel, good enough to measure objects as small as 30 inches (75 cm) across.

Engineers at Ball Aerospace in Boulder, Colorado, designed and built the camera. We call it "The People's Camera" because we process and release images quickly, provide tools to make it easier to examine these enormous images (which can contain up to 500 megapixels), and welcome suggestions from the public.

Make a wish

HiWish is our public web tool for suggesting images. It's easy to register and propose places on Mars you'd like HiRISE to photograph. Since we announced the HiWish program in early 2010, 9,248 people have registered, and they have put forward 21,021 targets. Sometimes a single photo can satisfy more than

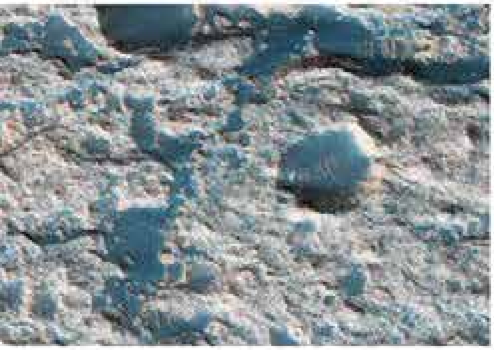




Far left: Images taken as part of the HiWish program cover much of Mars. Each square indicates one of the 5,438 photos captured during the program's first eight years. The base map shows the altitude of the surface (red signifies high, blue low) from the Mars Orbiter Laser Altimeter on Mars Global Surveyor. NASA/JPL/USGS/UNIVERSITY OF ARIZONA

Left: Glacial features appear across many high-latitude mountainous regions on Mars. Here, snow and ice accumulated in the mountain valley at top and then flowed downhill onto the adjacent plain. In some cases, such glaciers have long since lost their ice; in others, ice remains beneath a cover of rock and soil debris.

Top: Sand dunes line the valley floor in this 0.6-mile-wide (1 kilometer) section of Samara Valles. This entire ancient valley system runs more than 620 miles (1,000 km) across the heavily cratered southern highlands before emptying into Chryse Basin.



Above: Bumps and knobs occupy this tiny section on the floor of Palos Crater. Scientists think this terrain is weathering into polygon-shaped blocks. Winds brought in the dark sand and dust that fills the eroded, circular impact craters.

Right: Martian gullies occur on steep slopes, most often on the walls of craters at middle and high latitudes. Typically, a gully shows a branching pattern at its head and a fan-shaped debris apron at its base. Some scientists think liquid water carves the gullies, while others believe they form as chunks of frozen carbon dioxide roll downhill.

NASA's Mars Reconnaissance Orbiter has sent more data to Earth than all other interplanetary missions in history combined.

As of the beginning of this year, HiWish has fulfilled 7,000 requests by capturing 5,483 images, about 10 percent of HiRISE's total.

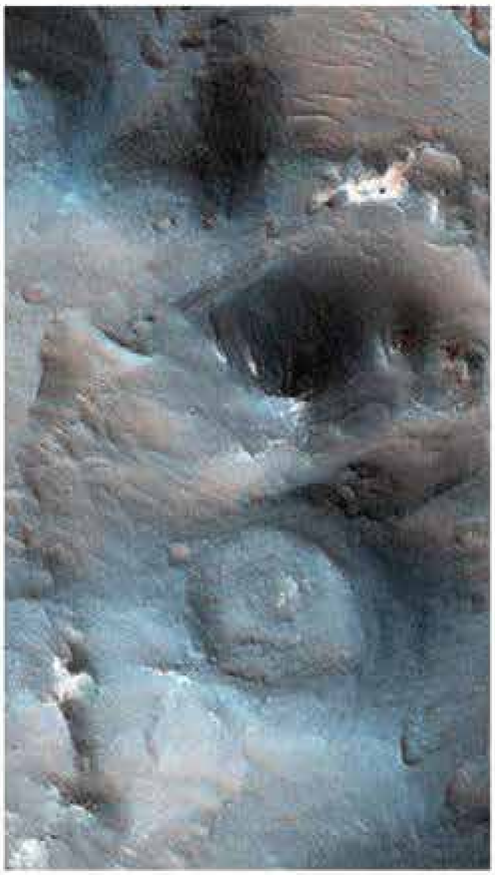
one suggestion if the locations lie close enough to one another. As of the beginning of this year, HiWish has fulfilled 7,000 requests by capturing 5,483 images, about 10 percent of HiRISE's total.

A HiWish user first decides what he or she wants to image, then writes a brief science justification and selects one of 18 science themes. (See "The 18 science themes," starting on p. 25, for descriptions.) Next, a member of the HiRISE science team prioritizes suggestions in each theme. A science lead chooses which of these to favor in each two-week MRO planning cycle. The decision takes into account several constraints, including the recommended priorities and what regions MRO will be able to view during that two-week window.

We typically need at least one image per 120-minute orbit to make optimal use of the downlink, or data stream, to Earth. HiRISE photos are so large that we can't store more than a few of them on board the spacecraft at a time; luckily, NASA's Deep Space Network provides downlink coverage every day. But if we take too few images, we will have transmitted all of our data and be left with valuable downlink that goes unused.

Some regions of Mars are extremely popular for imaging. The landing sites for Mars rovers, candidate sites for future landers, and Valles Marineris — the vast canyon system than spans some 2,500 miles (4,000 kilometers) — rank among the favorites. Other regions prove less popular, and orbits that pass over these areas have fewer suggested images. If we don't acquire any images during these unpopular orbits, we can run out of data to return and waste downlink. Fortunately, a HiWish suggestion is almost always available, and they often produce exciting results.

If you look at the global distribution of images acquired through the HiWish program (see p. 22), you'll see only a smattering in Mars' polar regions. This may be because the base maps people use to target the camera are incomplete or



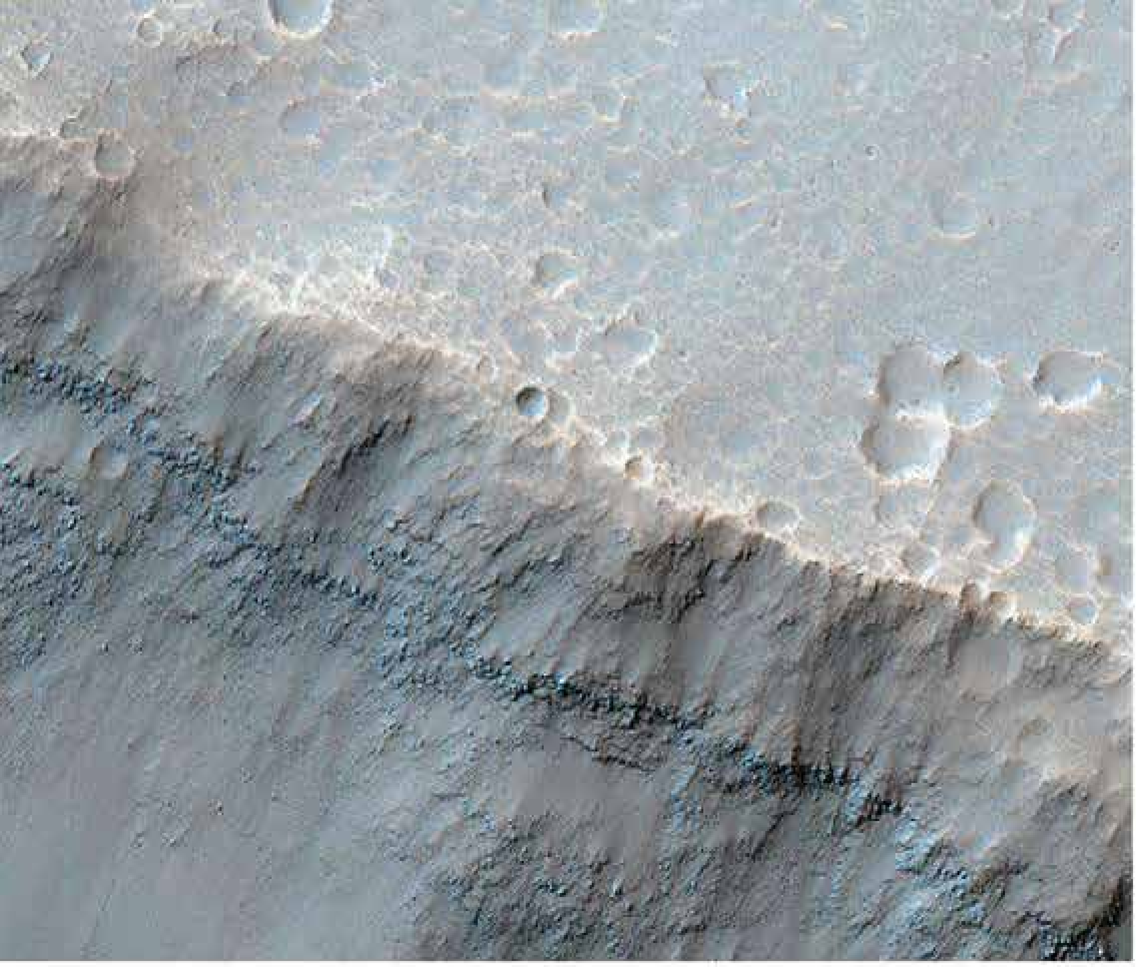
Clockwise from bottom left: These steep, conical hills in Valles Marineris were built up from debris expelled by volcanic vents. With only a few small impact craters on their flanks, these volcanic structures likely are only a few hundred million years old.

HiRISE discovered "recurring slope lineae" — the dark, narrow streaks that appear to flow down steep slopes and grow, fade, and reappear every martian year — that some scientists think could be seasonal flows of briny water. This HiWish image shows several originating in the boulder-strewn terrain at left.

The edge of a single mesa snakes through this view of Aureum Chaos, a broad region of plateaus and mesas near the equator. The rocks here likely formed as layers of sediments or volcanic debris. The ground later collapsed to create the current landscape.

The sand dunes at the base of this huge mesa might make a good dirt track course in the distant future. Racers would have to navigate the 8.7-mile (14 km) course under a gravitational pull barely one-third that at Earth's surface.

Channels circle around and, in some cases, apparently empty into a small crater in Mars' Arabia Terra region.



THE 18 SCIENCE THEMES

Aeolian (wind) processes: Looks at landforms sculpted by the fierce martian winds. Outside the polar regions, this is the planet's most dynamic geological process.

Climate change: Focuses on evidence for ongoing changes in Mars' climate by detecting signs that water and carbon dioxide are moving from one reservoir to another.

Composition and photometry: Uses the camera's high resolution to map areas of different compositions at small scales.

Fluvial processes: Targets features carved by flowing water to learn how they formed and to better understand the history of water on Mars.

Future landing sites: Analyzes the surface and hunts for potential hazards in areas scientists are considering for upcoming landers and rovers.

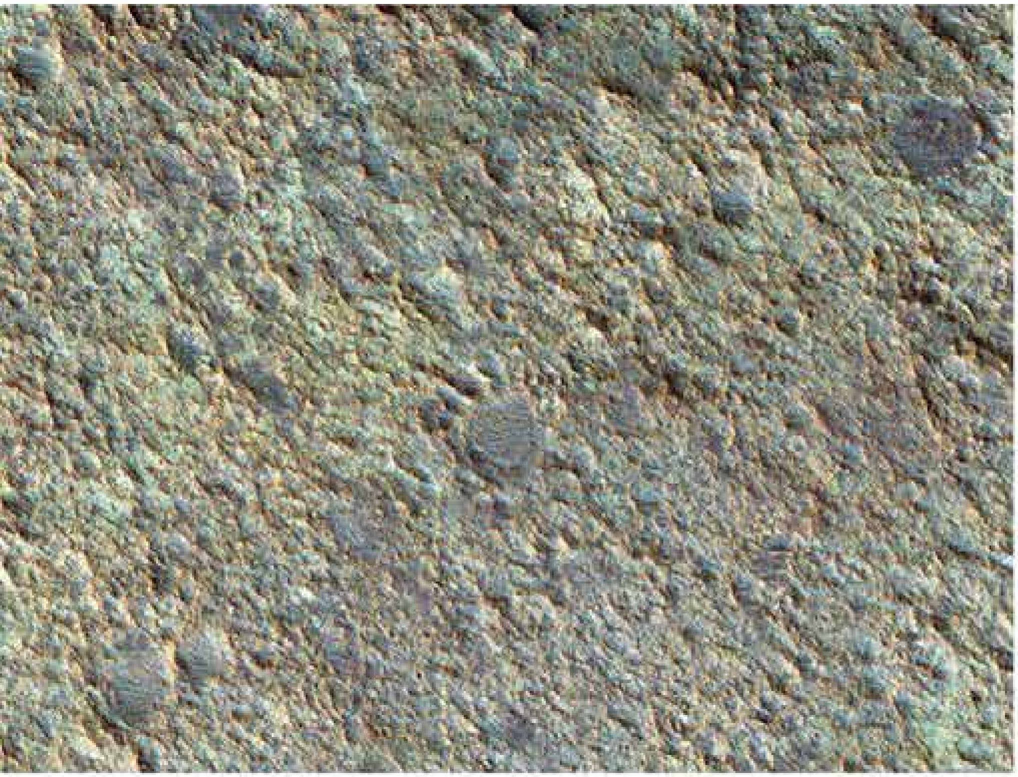
Geologic contacts and stratigraphy: Looks at the way different kinds of layered rocks are arranged to determine their relative ages and how the rocks were deposited.

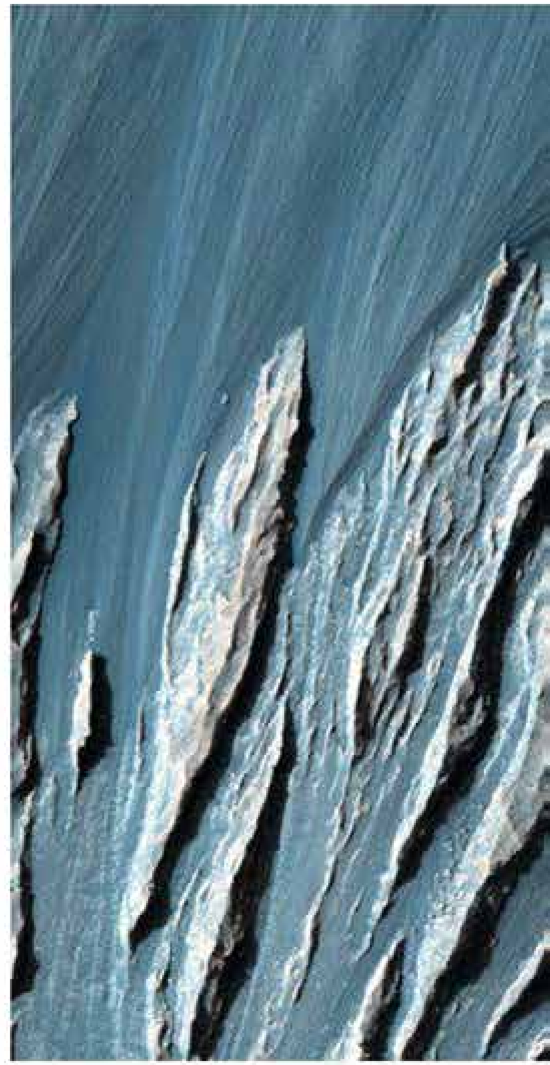
Glacial processes: Studies glaciers and their margins to learn about the distribution of water ice beneath Mars' surface as well as the history of surface ice and climate.

Hydrothermal processes: Examines features and deposits that might have formed in the presence of water warmed, for example, by volcanic activity or an impact.

Impact processes: Focuses on primary and secondary craters formed in high-velocity impacts, to study the physical properties and ages of various terrains.

— Continued on page 27





difficult to interpret at high latitudes. Away from the poles, the distribution is remarkably uniform in comparison to a map showing all HiRISE images, which concentrate strongly in certain locations. This happens because we commonly acquire HiWish images in regions that would otherwise have few science targets.

Above: This patterned ground lies in an area of exposed bedrock in the ancient martian highlands. The polygonal patterns likely arise from deposits of wet, clay-rich materials. This area resides in a valley network carved by flowing water billions of years ago.

Star performers

HiWish users include scientists who are not part of the HiRISE team, and as you might expect, they enter great science suggestions. University of Hawaii researcher Peter Mouginis-Mark proposed the first HiWish image we acquired: a view of ejecta flow from the 15.4-mile-wide (24.8 km) crater Arandas. Some of our favorite HiWish requests come from Ken Edgett of Malin Space Science Systems in San Diego. Edgett is the principal investigator for the Mars Hand Lens Imager on the Curiosity rover and was the top planner of photos captured by the Mars Orbiter Camera on the Mars Global Surveyor satellite from 1997 to 2006. Roughly 100 other Mars scientists have suggested targets, and the resulting images have contributed to hundreds of publications.

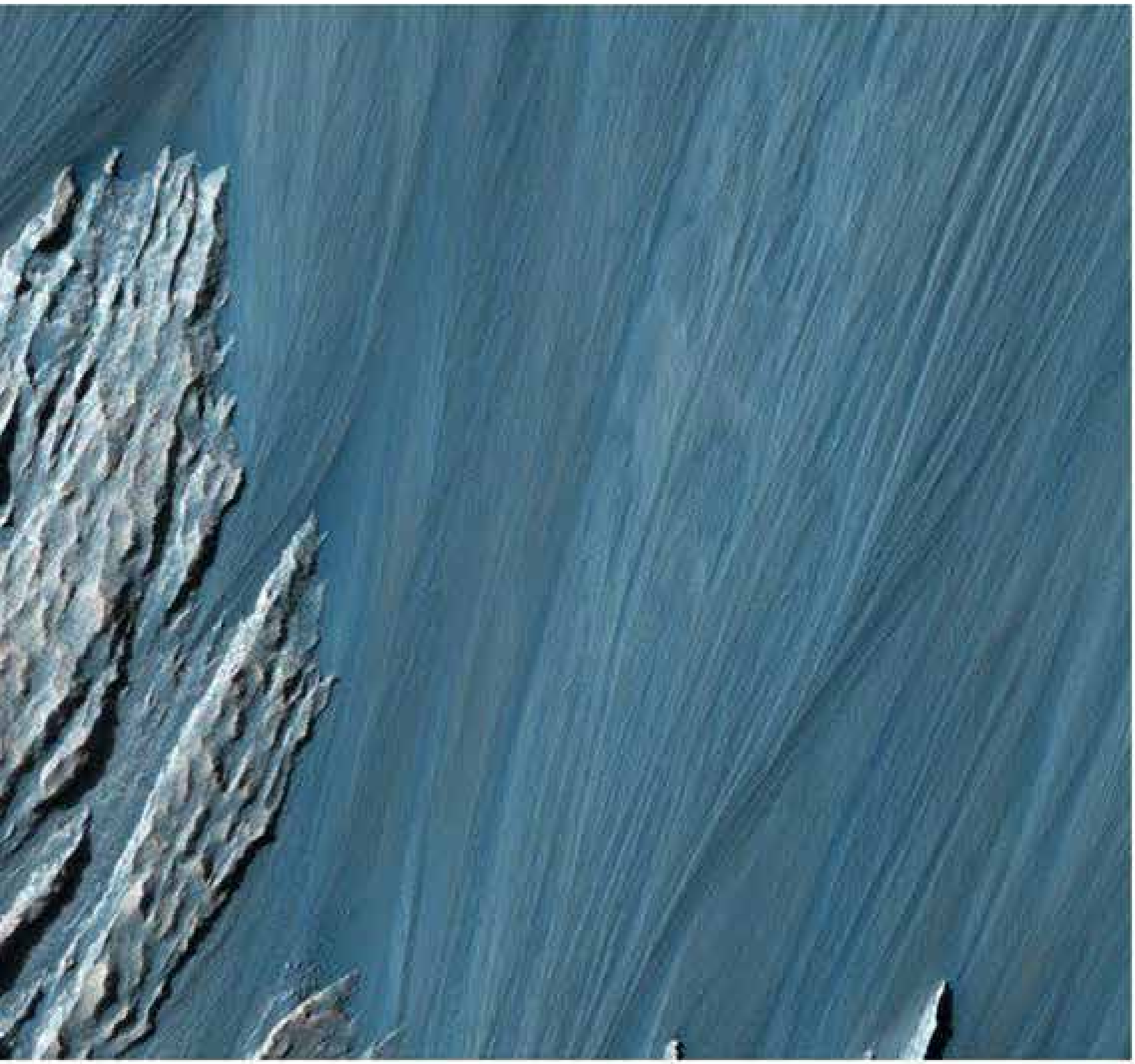
Still, you don't need to be a Mars scientist to propose excellent targets.

Roughly 100 Mars scientists have suggested targets, and the resulting images have contributed to hundreds of publications.

Although each proposal needs a science rationale, it can be something as simple as "This hill looks like a volcano in lower-resolution images or topography, but we need a better image," or "This feature is especially bright in THEMIS nighttime infrared images — I wonder what it is."

THEMIS — the Thermal Emission Imaging System aboard NASA's Mars Odyssey spacecraft — photographs the martian surface at five visible-light wavelengths and 10 infrared wavelengths. Areas that appear bright in the infrared at night are warm and thus typically rocky, and bedrock makes a great subject for HiRISE. Regions that appear dark and featureless at night are cold and tend to be covered with dust. Such locations typically make less interesting targets for high-resolution photography, though with some important exceptions, like new impact sites.

Some HiWish users may be disappointed with their images if they target regions blanketed in dust. Although some of these landforms may draw your attention in lower-resolution images or through their topography, the new details HiRISE reveals might be nothing more than textures in the dust. Intriguing targets do exist in dust-covered regions, but the key is to think about what you might



From top: Dark debris eroding off a mountain (off the top of this image) collects at the base of a cliff near the center of Hebes Chasma. Shades of blue are not natural on the Red Planet, of course — scientists enhance color to better see fine differences.

This tangle of ridges forms just a small part of a much wider network of similar ridges north of Baldet Crater. Individual ridges can be 1,000 feet (300 m) long and 100 feet (30 m) tall.

Dozens of large boulders dot the surface of this tiny crater and its immediate surroundings. The region lies in a series of glacial ridges in the northern hemisphere.

Channels cut through this intricate series of mesas and buttes that lie in the northern lowlands, northwest of the giant Elysium Mons volcano.

— Continued from page 25

Landscape evolution: Seeks the subtle signatures that allow scientists to understand the processes that shape the planet's diverse landscapes.

Mass wasting processes: Studies the downhill movement of rocks and debris, from massive landslides and debris avalanches to single boulders rolling down a hill.

Polar geology: Explores the layered deposits in both the north and south polar regions, to help unravel the planet's climate history.

Rocks and regoliths: Examines rocks as well as the smaller rock pieces and dust (regolith) that make up the martian soil, to see what processes create this soil over time.

Seasonal processes: Studies the transient polar caps of carbon dioxide frost as they wax and wane (through condensation and sublimation, respectively) with the seasons.

Sedimentary/layering processes: Seeks insights into Mars' layered rocks to learn when the layers formed and if they began as sediments in lakes, volcanic ash, or atmospheric dust.

Tectonic processes: Explores the forces within the planet's interior that cause rock to slide, bend, and break, by measuring how much the rock has deformed.

Volcanic processes: Focuses on the planet's huge volcanoes and extensive lava flows, in part to learn if the lava oozed from the ground or blasted out in massive explosions.

Other (non-themed): Any potentially interesting observation that doesn't relate directly to one of the other 17 themes.

The greatest HiWish success stories are the probable discoveries of the Mars 3 and Beagle 2 landers.

WEBSITES TO GET YOU GOING

The scientists behind the HiWish program have developed tools to make it easy to plan your imaging adventures with HiRISE. Here are some websites to help you get started:

HiWish home page:
www.uahirise.org/hiwish

NASA's initial announcement about the HiWish program:
www.jpl.nasa.gov/news/news.php?release=2010-018

The first HiWish image acquired:
www.uahirise.org/ESP_016842_2225

HiView, a tool for viewing full-resolution HiRISE images:
www.uahirise.org/hiview

Help analyze HiRISE images:
www.planetfour.org

James Secosky's Wikipedia page for the HiWish program:
https://en.wikipedia.org/wiki/HiWish_program

THEMIS images and background:
https://themis.asu.edu

The Mars 3 lander story:
https://tinyurl.com/yc6xlstj

The Beagle 2 discovery story:
https://tinyurl.com/m9tnwsn

see at a scale of several feet. The best way to do this is to examine nearby HiRISE photos at full resolution. You can download a tool called HiView from the HiRISE website that lets you rapidly examine any image at full resolution.

Of the 5,483 HiWish images, retired schoolteacher James Secosky suggested 2,133 — nearly 40 percent of the total. He is also largely responsible for the excellent Wikipedia page about HiWish. The page includes many of his favorite HiWish images broken down into 35 categories. Secosky chooses his desired locations by first examining photos taken with MRO's Context Camera (CTX), which provides a resolution of about 20 feet (6 meters) per pixel. Features that look interesting in a CTX image usually make great targets for HiRISE.

Many proposals come from students. Over the past decade, Ginny Gulick of NASA's Ames Research Center in Moffett Field, California, has helped students at Evergreen Middle School in Cottonwood, California, suggest and analyze HiRISE photos. And students taking my Mars class at the University of Arizona have been targeting and analyzing HiRISE images since 2007.

In search of lost landers

The greatest HiWish success stories are the probable discoveries of the Soviet Union's 1971 Mars 3 lander and the United Kingdom's 2003 Beagle 2 lander, which hitched a ride to the Red Planet on the European Space Agency's (ESA) Mars Express mission.

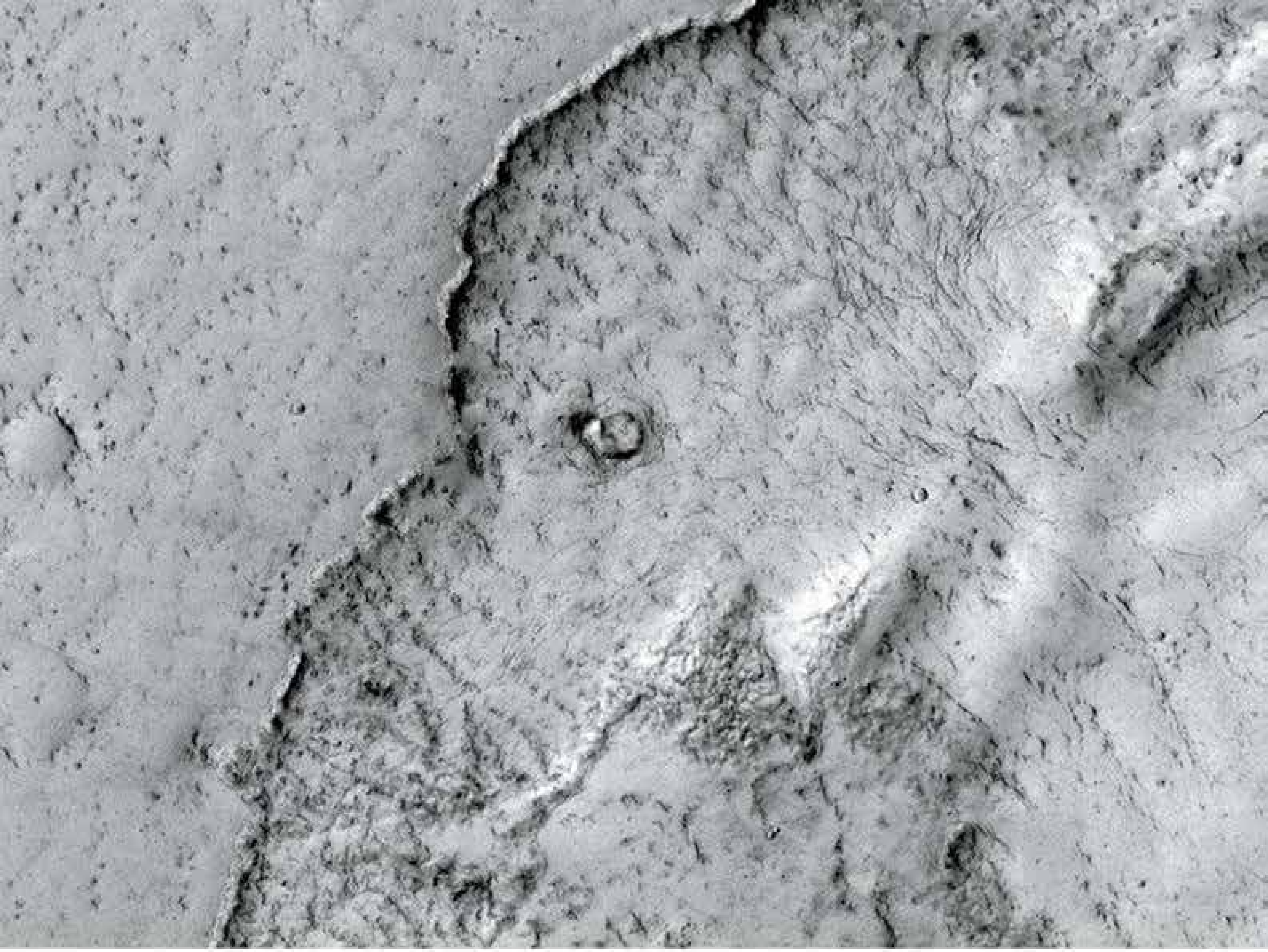
Imaging successful landers is quite easy because we know exactly where to look for them and what pieces to find — typically a back shell and attached parachute, a heat shield, and the lander itself. But lander missions that failed to call home are much more difficult to find or recognize because they could lie within a large region of the planet and we don't know for sure what to look for. If the spacecraft crashed, there might be only a small fresh crater. If the spacecraft's

parachute opened, it might create a bright target that would be relatively easy to see, and the other pieces may appear bluer, or at least less red, than a typical martian surface. Unfortunately, any such artifacts get covered by dust over time and may closely resemble natural features in HiRISE images.

Finding these lost landers requires someone — or a team — with dedication, who also understands the details of the probe's landing system and the exact sizes of possible pieces. Russian journalist and space-exploration enthusiast Vitaliy Egorov led the Mars 3 discovery effort. In this case, at least, the spacecraft seekers had a bit of help: We know that Mars 3 landed mostly successfully because it returned a signal for about 15 seconds before going silent for still-unknown reasons. The team found an exceptional candidate for Mars 3's parachute and more subtle features that could be the descent module, heat shield, and lander itself.

As for Beagle 2, the HiRISE team launched a concerted effort to image the spacecraft's landing ellipse — the region within which the probe likely set down if the entry and descent went according to plan. A 1-sigma landing ellipse means there's a 39 percent chance the craft lies in that area; a 3-sigma ellipse raises the probability to 99 percent. Although our team imaged most of the 3-sigma ellipse, nobody was able to spend the time needed to thoroughly examine each image.

Meanwhile, Michael Croon, a retired ESA engineer who worked on the



Clockwise from top left: Layers of dusty ice up to 2 miles (3 km) thick and about 620 miles (1,000 km) in diameter form the north polar layered deposits. The exposed layers seen here have various surface textures, hinting that the underlying layers have a different dust content or ice-grain size. The angular breaks mark where layers eroded before new ones were deposited.

The human brain does a remarkable job of perceiving familiar shapes when they aren't really there. In this HiWish image, one of the author's favorites, the boundary of a lava flow looks like the head and trunk of an elephant; a well-placed crater forms the pachyderm's eye.

Have you ever found a needle in a haystack? Then you might be ready to search HiRISE images for artifacts from defunct spacecraft. A team of Russian space enthusiasts used a HiWish request to locate what appears to be the parachute from the 1971 Mars 3 lander. The original image measures 3.1 miles (5 km) across; the suspected white parachute (inset, center) is just 25 feet (7.5 m) in diameter.

If you haven't tried HiWish, what are you waiting for? MRO arrived at Mars 12 years ago, and it will not last forever.

operations team for Mars Express, was searching the region more carefully. He entered a HiWish suggestion with this eye-catching science rationale: "I located Beagle 2 hardware candidates inside the 1-sigma landing ellipse, see my map … I suggest re-imaging the location (90.429E 11.526N) in color to check if the putative lander exhibits a color anomaly."

After reading this, I made sure we acquired the requested image, which supported his interpretation. We also took additional photos, and the full set showed something remarkable: Bright spots appeared at the location of the suspected lander, but at slightly different locations in different images. We explained this as specular reflections — the type you get from a mirrorlike surface — off the solar arrays and the lander science package, each of which should be positioned on the ground at a slightly different angle.

Because we acquired HiRISE images over a range of illumination and viewing angles, sometimes we got a specular reflection from one panel and sometimes from another. We identified four such bright spots spaced just right to be from the deployed lander, so at least three of the four solar panels had deployed correctly. This meant that the Beagle 2 entry, descent, and landing sequence was largely successful, a vital piece of information to engineers planning future landings on Mars.

Although HiRISE has captured thousands of images through the HiWish program, literally thousands of other intriguing targets remain unexplored. If you haven't tried HiWish, what are you waiting for? MRO arrived at Mars 12 years ago, and it will not last forever. Heed Janis Joplin's advice from the last song on her classic *Pearl* album: "Get it while you can."

Planetary scientist ***Alfred McEwen*** *of the University of Arizona is the principal investigator for HiRISE.*

Clockwise from bottom left: This crater's oval shape suggests that it formed when an asteroid collided with Mars at a shallow angle. The impact gouged out the 1,000-foot-wide (300 m) divot and sent most of the debris at right angles to the impactor's direction.

This collection of streamlined hills, known as yardangs, lies in the Arsinoes Chaos region in far eastern Valles Marineris. They form when winds erode bedrock either by sandblasting the surface with tiny particles or carrying away loosely bound pieces. Scientists are still trying to learn how the series of parallel sand ridges between the yardangs formed.

Looking for signs of past water and possibly life on Mars, scientists initially chose 28 potential landing sites for the Mars 2020 rover mission. This image shows layering in one of those spots: 56-mile-wide (90 km) Firsoff Crater. Scientists have since dropped this site from consideration.

The distinctive shapes of these sand dunes in Hellas Basin arise because the wind blows in the same direction (east to west) for long periods. By imaging regions like this over many years, scientists can measure how fast the dunes creep across the surface.

This close-up shows flows of ice-rich debris along the edge of a mesa near the boundary between martian lowland and highland terrain. Scientists think material deposited only about 10 million years ago covers much of the area.

Above: These concentric cracks mark a crater that formed when the surface collapsed. Scientists think a mudflow covered the original landscape, which was rich in water or water ice. A nearby source of magma then either quickly turned the water to steam or melted the subsurface ice, triggering the collapse.

Minting a celestial

Coins made as far back as 400 B.C. may honor solar eclipses. The tradition continued for two millennia.

text and images by Richard Jakiel

The Great American Eclipse of August 21, 2017, certainly was one for the record books. It became a huge media event, and hotels and even state and national parks were booked to capacity in anticipation. But total solar eclipses have not always been seen with the same kind of awe and wonder. In ancient times, people often experienced great fear and trepidation, and they viewed such events as omens or portents of change.

The earliest verifiable eclipse observation was made June 15, 763 B.C., by the Assyrians. This was soon followed by well-documented viewings recorded by the Chinese and Greeks. But it was the Chaldean astronomers of the Neo-Babylonian Empire who first deduced the Sun-Moon eclipse connection known as the saros cycle.

This period, 6,585.3211 days, is the length of time after one total solar eclipse when a nearly identical eclipse will occur. Armed with this new knowledge, the Chaldeans, and later the Greeks and Romans, could explain the cause of eclipses and — more importantly — predict when they would happen. This allowed the Romans to use eclipses as a propaganda device to promote military campaigns or political agendas.

The mints open

Around the same time, the Greeks came up with a pretty nifty invention — coinage. At first the designs were quite crude, but in the span of a few generations, they became nothing less than works of art. The sheer variety of themes soon rivaled the number of Greek city-states scattered throughout

Fourth century B.C.

This silver coin from the Greek city-state of Istros is smaller than a dime, yet twice as thick. Two heads (one inverted) of Apollo appear on the obverse, and the reverse shows an eagle carrying off a dolphin. These coins might commemorate two solar eclipses, one in 434 B.C. and another a scant three years later in 431 B.C.

November 11, 120 B.C.

The mint of M. Tullius in the Roman republic issued this dime-sized silver coin, called a denarius, after the hybrid-total eclipse on November 11, 120 B.C. The obverse features the winged head of Victory, and the reverse shows a chariot drawn by four horses. Above is a wreath of fire representing the eclipsed Sun.

January 5, A.D. 75

A denarius with the Rogman emperor Vespasian on the obverse and a ship's prow plus a "star" (the eclipsed Sun) on the reverse was produced to commemorate the total solar eclipse of January 5, A.D. 75, and probably to celebrate renewed stability in the Roman Empire.

memory

the Mediterranean world.

Starting in Greece, those who minted coins used them in ways beyond their stated use as money. Commemorating an event or a person could curry favor with those in power. Honoring natural events — such as eclipses, which would have been experienced by many — or military victories could instill within the populace a sense of unity or nationalistic pride. What finally appeared on individual coins was up to the imagination of the minter.

One of the most unusual designs came from Istros, a small city-state on the coast of the Black Sea near the mouth of the Danube River. Made from about 400 B.C. to 350 B.C., the coins featured two inverted identical heads of the god Apollo, always presented anti-parallel, on the obverse (front). Scholars have offered a number of explanations for the heads, including that they represented the rising and setting Sun, that the pair was supposed to be the Dioscuri (the twins Castor and Pollux), and even that the heads symbolized branches of the river Ister (Danube).

But in 2005, William C. Saslaw and Paul Murdin from the Institute of Astronomy at the University of Cambridge in England hit upon the idea that these coins commemorated solar eclipses. In a span of only three years, there were two solar eclipse events: The first occurred at 6:30 A.M. on October 4, 434 B.C., when the heavily eclipsed Sun rose out of the Black Sea. (The line of totality lay about 100 miles [160 kilometers] north.) In fact, the rising Sun would have appeared as a thin crescent, and in the span of 10 minutes, the tips of its "horns" would have switched to point in the opposite direction, much like the inverted heads. Three years later on August 3, 431 B.C., during the Peloponnesian War, an annular eclipse visible from Istros produced the same horned solar crescent pattern, but this time in the late afternoon. Because Istros was a busy commercial center, regional officials spun these events as signs of good times, which may have resulted in producing this series of coins.

Unlike Greek coins, which can be notoriously hard to date due to a number of factors, several series of Roman eclipse coins have been linked to events. Perhaps the earliest, and certainly one of the most intriguing, was minted from 217 B.C. to 215 B.C. The Roman Republic was locked in the Second Punic War with Carthage and had already lost several major engagements to the great general, Hannibal Barca.

A.D. 126 to 128

One of the most sought-after series of "star and crescent" coins was made during the reign of the Roman emperor Hadrian. Inspired by the eclipse of September 3, 118, whose path fell on the northern part of the Roman Empire, the series features a portrait of Hadrian on the obverse and a thin crescent Sun with one to seven "stars" on the reverse. The reverse of the coin on the left has a single star; the center one has five stars; and the one on the right contains seven stars. This series of silver denarii was minted from 126 to 128 during the middle part of Hadrian's reign.

ILLUSTRATIONS FROM TOP: TARONIN/DREAMSTIME; SDPCREATIONZ/DREAMSTIME

Perhaps out of sheer desperation, the Roman ruling class saw the total solar eclipse of February 11, 217 B.C., as an omen of better things to come. To honor it, Rome produced an unusual bronze coin with a radiant visage of Apollo; the reverse had an almost whimsical "smiley face" consisting of a solar crescent, two stars, and a pellet. Did it help achieve the desired soothing effect? It's hard to say, but in the end the Romans did eventually triumph.

One hundred years later, fortunes had greatly improved for the Romans with major victories over the Celts of southern Gaul (France). A series of coins was minted to commemorate the eclipse of November 11, 120 B.C., which was seen as a blessing by the gods. The eclipse was a hybrid-annular type, much like the May 30, 1984, event in the eastern United States.

The reverse of the coin features a winged Victory driving a chariot of four horses with a fiery wreath burning in the sky. It doesn't take too much imagination to see that the wreath is the eclipsed Sun, with Bailey's beads and large prominences dotting the rim.

A new era dawns

By the turn of the first century A.D., Rome had become a mighty empire, spanning across the entire Mediterranean Sea and much of Europe. After several years of turmoil following the end of Nero's chaotic reign, stability finally returned under the no-nonsense reign of Vespasian.

On January 5 in the year 75, a total solar eclipse was seen in southern Italy and northern Africa. In Rome, more than 90 percent of the Sun was obscured. Perhaps to mark the start of more good times, the mints produced a silver denarius — a dime-sized silver coin — displaying a ship's prow with a brilliant star (the eclipsed Sun) above it, guiding the ship to safe waters.

Perhaps the most beautiful and well-known series of Roman eclipse coins appeared during the height of the empire. The first series of silver denarii was minted from 126 to 128, during the early part of the reign of the emperor Hadrian. The reverse of these coins shows a thin crescent plus one to seven stars, with four- and six-star versions being the rarest of the set.

Many scholars had thought that this crescent represented the Moon. Our satellite's crescent phase is a normal occurrence, however, and if the seven stars were the five planets plus Earth and Moon, why repeat? An eclipsed Sun is a better explanation. And indeed, on September 3, 118, a spectacular total solar eclipse cut across the northern Roman Empire. This event certainly could have provided the artistic inspiration for the coin series.

An even longer lasting eclipse coin series was minted during the Roman Severan dynasty. On December 28, 186, people in the region of the western Mediterranean watched an annular eclipse setting in the winter sky. From Rome, the Moon covered more than 70 percent of the Sun, which appeared as a brilliant crescent as it sank below the western horizon.

For seafarers and citizens of Rome, this celestial spectacle must have been an awesome sight. As for the coin series, it was minted primarily in bronze for more than four decades (and through the reign of several emperors). It also featured a crescent with one to seven stars.

Through the centuries, the Greeks and Romans minted thousands of different coins with astrological and astronomical motifs, yet few are the subjects of research. Several years ago, fellow amateur astronomer and collector Jerry Armstrong contacted me regarding a small coin from the Roman province of Lydia in western Turkey. The design on the reverse consisted of a crescent and two stars — but was it an eclipse coin?

After a bit of research, we found that a total solar eclipse occurred August 14, 212, with the path running across the Black Sea, southern Europe, and just south of Rome. In Lydia, the lunar disk covered more than 95 percent of the Sun, while ships just offshore would have been treated to totality. Because the coin was minted between 212 and 215, the correlation is good. But what was the significance of the stars? They were the bright planets Jupiter and Venus, and both would have been easily visible during totality.

The Middle Ages

By A.D. 1000, nearly all aspects of the ancient Roman world were gone. Christianity and Islam had replaced pagan

August 14, A.D. 212

This small bronze coin, about the size of a penny, was produced shortly after the eclipse of August 14, 212, in the Roman province of Lydia in western Turkey. From there, the Moon covered 95 percent of the Sun. Of interest are the two "stars" on the reverse. They represent Jupiter and Venus, both of which would have been easily visible to the unaided eye during the event.

A.D. 1176

During the Middle Ages, it was common to interpret astronomical events such as solar eclipses as signs from the heavens. This silver denarius was minted in Antioch during the reign of Bohemond III. It sports a simple design, a commemoration of the total solar eclipse of 1176, whose path of totality passed directly over the city.

beliefs. However, astrologers still were making predictions about the future. They, as well as the general population, saw solar eclipses and comets in particular as omens of change, and coins depicting those events were commonplace. Let's examine the circumstances of a few examples and their impact on the feudal world.

One of the most infamous of all English rulers was John Lackland, better known as King John, the youngest brother of Richard the Lionhearted. Much maligned by history, John had a disagreeable personality that offset whatever good traits he may have had. But he seldom let an opportunity for self-promotion go by. In 1201 and 1207, the tracks of two annular eclipses passed quite close to the British Isles. In London, observers would have seen the Moon covering 67 percent and 76 percent of the Sun's disk, respectively.

King John issued a series of coins inspired by the two events, perhaps as a propaganda device to promote good times, or to shore up his failing reign. The coin depicts a crescent Moon and a stellate Sun. In the long run, it didn't seem to do him much good; he was forced to sign the Magna Carta in 1215, and he died of dysentery less than a year later.

Luckily, King John wasn't the only game in town. For several centuries, the Crusades had a huge impact on everyday life, and during that time, eclipses were used to promote great victories and other events. A popular example was minted in Antioch during the reign of Bohemond III. This city was on the centerline of the total solar eclipse of April 11, 1176, and the event was likely a major influence on the design of a silver coin.

Another eclipse that inspired the creation of several coins took place six decades later. The path of totality of the great eclipse of June 3, 1239, cut across Asia Minor and most of southern Europe. The greatest duration of totality was 5 minutes and 59 seconds. A scant two years later, on October 6, 1241, another total eclipse crossed southeastern Europe.

These events had a major impact on coin design across the region for several decades. A couple of fine examples include a silver coin from Slavonia (Croatia) and an exotic coin from the Sultanate of Rum showing an attacking lion with the Sun and three luminaries — possibly Venus, Saturn, and Mercury.

The Enlightenment and beyond

By the early 18th century, the science of eclipse prediction had progressed to a point where astronomers could accurately pin down the location and duration of the paths. However, it would take much longer for the general populace to drop the old superstitions and accept the science. Classic examples are the medallions produced by both sides of the conflict at the end of the Siege of Barcelona (April 2–27, 1706) during the War of the Spanish Succession.

As a large English fleet pulled into the harbor carrying reinforcements, the siege was quickly lifted, and Spanish and French forces soon began to leave the city. On the morning of May 12, the retreating forces witnessed more than four minutes of totality. It didn't take long before people were calling the event the "eclipse of the Sun King," referring to Louis XIV of France. On the side of the victors, Queen Anne of Britain had bronze and silver commemorative medals produced, the reverse depicting Barcelona Harbor and the radiant eclipsed Sun rising over it.

On the losing side, the Habsburgs produced a medal for King Charles III of Spain showing a similar scene on the reverse. But instead of a tranquil harbor, it displays the eclipsed Sun over a city under siege with the phrase along the rim "VNIVS LIBERATIO ALTERIVS OPRESSIO," or "the liberation of one(s), oppression of others."

Today, we no longer regard total solar eclipses with mystery and dread, although we still celebrate them in coins and medals. And thanks to the internet, we have relatively easy access to resources that let us conduct research on eclipse coins.

The Greeks and Romans produced literally tens of thousands of different coins, and thousands more were minted in the Middle Ages. Many have not yet been cataloged, let alone examined for possible connections to astronomical events. It's still a wide-open field, limited only by your ability to do online research. Give it a shot — you might just make an interesting discovery!

Richard Jakiel *writes about astronomy's history and observes celestial objects from Lithia Springs, Georgia.*

A.D. 1201 and 1207

A stylized portrait of King John Lackland of England — the villainous "Prince John" of the Robin Hood stories — is shown on the obverse of this thin silver coin. On the reverse is a crescent Moon plus a starlike Sun. The minting of this coin, perhaps used as a propaganda device to herald future good tidings, commemorated annular eclipses in 1201 and 1207.

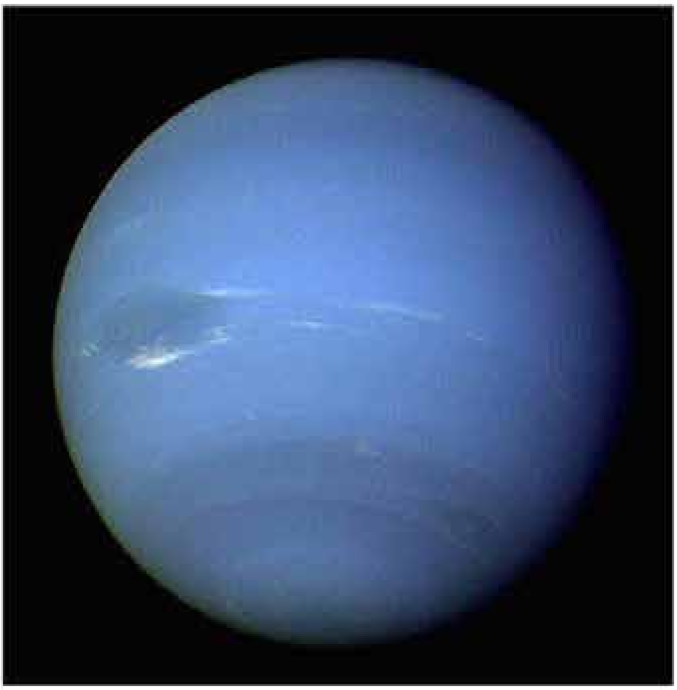
October 6, A.D. 1241

The total eclipse of October 6, 1241, broadly visible across Southern Europe and Asia Minor, had a major impact on coin design. This example from Slavonia (now Croatia) has a stoic design typical of those times. The obverse features a wolflike predator with two stars, while the reverse shows a cross surrounded by a star and crescent, a large star, and portraits of two rulers.

MARTIN RATCLIFFE and **ALISTER LING** describe the solar system's changing landscape as it appears in Earth's sky.

Visible to the naked eye
Visible with binoculars
Visible with a telescope

September 2018: Neptune at its best



Neptune appears at its best for the year in September. Although a telescope will show its tiny blue-gray disk, you won't see the stunning detail the Voyager 2 spacecraft revealed when it flew past in 1989. NASA/JPL

Four bright planets line up across September's early evening sky. Venus and Mars provide the bookends for this bonanza, with Jupiter and Saturn sandwiched between. You can look for Uranus and Neptune to come to the fore later in the evening. Neptune reaches opposition and peak visibility September 7, but it remains an inviting object all month. And Mercury rules the predawn sky early this month as it wraps up one of its finest morning appearances of the year.

Your first target these September evenings should be **Venus**. Earth's inner neighbor lies low in the west-southwest shortly after the Sun goes down. From mid-northern latitudes on the 1st, it appears about 10° high a half-hour after sunset. Despite its low altitude, it's easy to see because it shines brilliantly at magnitude –4.6. Use binoculars and you'll see Virgo's brightest star, magnitude 1.0 Spica, 1.3° to the planet's upper right.

Although Venus dips a hair lower each evening, it also grows brighter. It peaks at greatest brilliancy September 21, when it gleams at magnitude –4.8. It then stands just 5° high in the southwest 30 minutes after sunset, however, so you'll need an unobstructed horizon to get a good view.

Viewing Venus through a telescope in September reveals remarkable changes. On the 1st, the planet appears 30" across and 40 percent lit. By the 15th, it spans 36" but the Sun illuminates only 30 percent of its Earth-facing hemisphere. And on September's final evening, Venus shows a disk 46" in diameter and 17 percent lit.

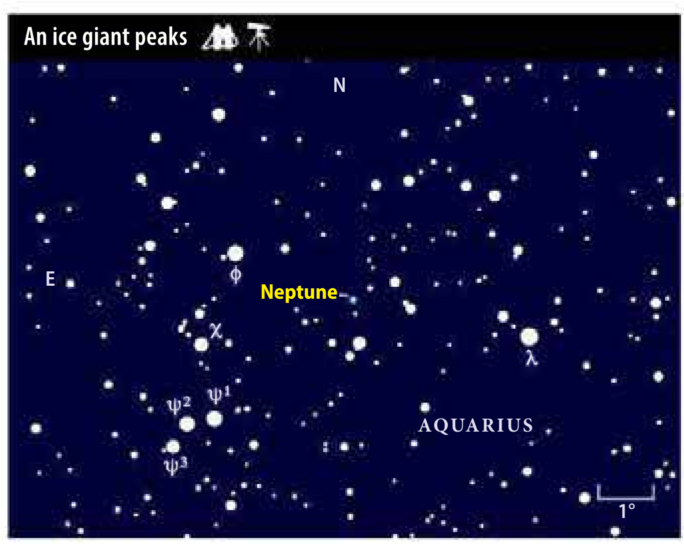
You can find **Jupiter** blazing in the southwest after sunset all month. It lies 23° to Venus' upper left September 1; the gap closes to 14° by the end of the month. Be sure to watch when the waxing crescent Moon slides past these planets. On September 12, our satellite lies 9° above Venus and 16° right of Jupiter. By the next evening, the Moon stands 4° to Jupiter's upper right. Although the magnitude –1.9 giant planet appears less than one-tenth as bright as Venus, it easily outshines every nighttime star.

If you want crisp views of Jupiter through a telescope, observe in late twilight before the planet sinks too close to the horizon. Low altitudes mean its light has to travel through more of Earth's image-distorting atmosphere, which washes out fine detail. For the same reason, views in early September should be sharper than those later on.

Jupiter's disk spans 35" at the beginning of the month. This is big enough that even small scopes will deliver striking views of atmospheric features. Look for two dark belts that straddle a brighter zone coinciding with the gas giant's equator. Changes within these belts often show up in just an hour of observing.

Small instruments also reveal Jupiter's four big moons: Io, Europa, Ganymede, and Callisto. The satellites shift positions noticeably within an hour or two, and will look completely different from one night to the next. The illustration on the right side of p. 41 will help you identify which moon is which.

Scan some 45° east of Jupiter, and your eyes will land on **Saturn** nestled among the background stars of northern Sagittarius. The magnitude 0.4 ringed planet lies due south and at peak altitude an hour after sunset



The eighth planet reaches opposition September 7, when it lies 2.3° west-southwest of 4th-magnitude Phi (ϕ) Aquarii. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

RISING**MOON**

On the Sea of Moisture's shore

Intriguing features abound on a waxing gibbous Moon. Marvel at Tycho's satellite-spanning rays, expansive Mare Imbrium with striking Sinus Iridum on its northwestern edge, and the prominent crater Copernicus with its intricate debris splatter.

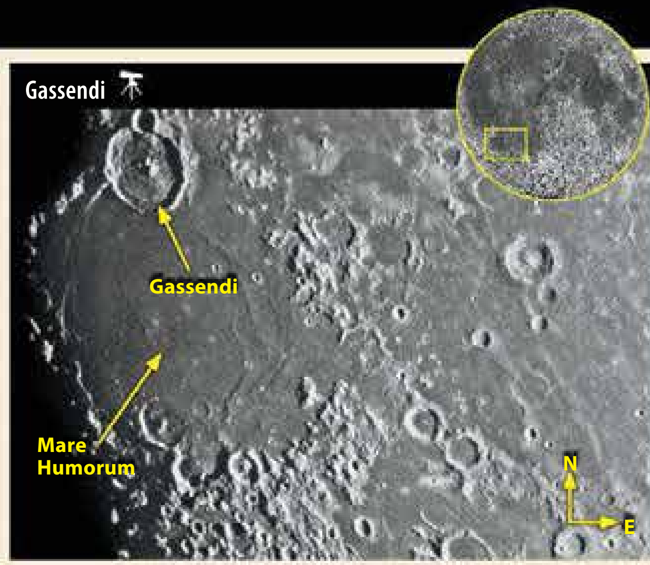
Consider starting your observing session before darkness falls, when the light-blue sky reduces the glare of the Moon's bright disk. Sometimes, the Moon at night is simply too bright through a telescope. A filter helps, but sunglasses provide a nice low-tech solution.

Target the Moon the evening of September 19, when Mars hangs some 5° below it. The sunrise line has moved past the fascinating crater Gassendi, which perches on the northern edge of Mare Humorum (Sea of Moisture) in the lunar southwest. Circular Gassendi spans 69 miles and tilts down toward the center of Mare Humorum.

Gassendi displays multiple peaks and slumped walls, a characteristic of many large craters. You can even see that the prominent crater on its northern rim formed after the main event and pushed this material inward. The arcs and rilles visible in the southern and southeastern parts of Gassendi are remnants of fracturing. Up and down motions of the crust caused surface cracks similar to those you might see in a pie crust. Lava later welled up from below and covered half of the crater's floor.

Scientists named this crater after 17th-century French astronomer Pierre Gassendi. In 1631, he became the first person to observe Mercury transiting the Sun.

Gassendi



The 69-mile-wide impact crater Gassendi boasts interior rilles and several central mountain peaks. CONSOLIDATED LUNAR ATLAS/UA/LPL; INSET: NASA/GSFC/ASU

September 1. Once the sky grows dark, you'll notice it is set against some of the Milky Way's richest regions. Binoculars reveal Saturn as a yellow sapphire with the misty glows of the Trifid Nebula (M20) 1.7° to the west and the Lagoon Nebula (M8) 2.2° to the southwest.

A First Quarter Moon interrupts the deep-sky viewing when it passes by September 16 and 17. Saturn's easterly motion against the starry background during September's second half carries it to a spot 2.2° east of M20 by month's end.

While binocular views of Saturn are thrilling, they can't match the extraordinary sight of the ringed planet through a telescope. Any scope shows the gas giant's 17"-diameter disk surrounded by stunning rings that span 38" and tip 27° to our line of sight, their maximum tilt of the year. Under good seeing conditions, you can spot the A ring poking

— *Continued on page 42*

METEORWATCH

Spy the false dawn

No major meteor showers occur in September, and the minor ones produce no more than five meteors per hour. But the tiny dust particles that give rise to meteors when they get incinerated in our atmosphere show up in a different way this month. Dusty debris from asteroid collisions and ancient comets fills the inner solar system. The particles concentrate along the orbital plane of the planets, called the ecliptic. And when the ecliptic angles steeply to the eastern horizon before dawn, as it does in September, the dust appears to the naked eye as a cone-shaped glow.

To see this zodiacal light, or false dawn, you must observe from a dark site when the Moon is out of the morning sky (September 8–23 this year). It appears most conspicuously within a half-hour of twilight's first glow.

The zodiacal light's predawn glow

Mid-September provides a good opportunity to see the cone-shaped zodiacal light (at left, beside the Milky Way) before dawn. JEFF DAI

OBSERVING HIGHLIGHT Neptune reaches its 2018 peak September 7, when the planet glows at magnitude 7.8 and spans 2.4" through a telescope.

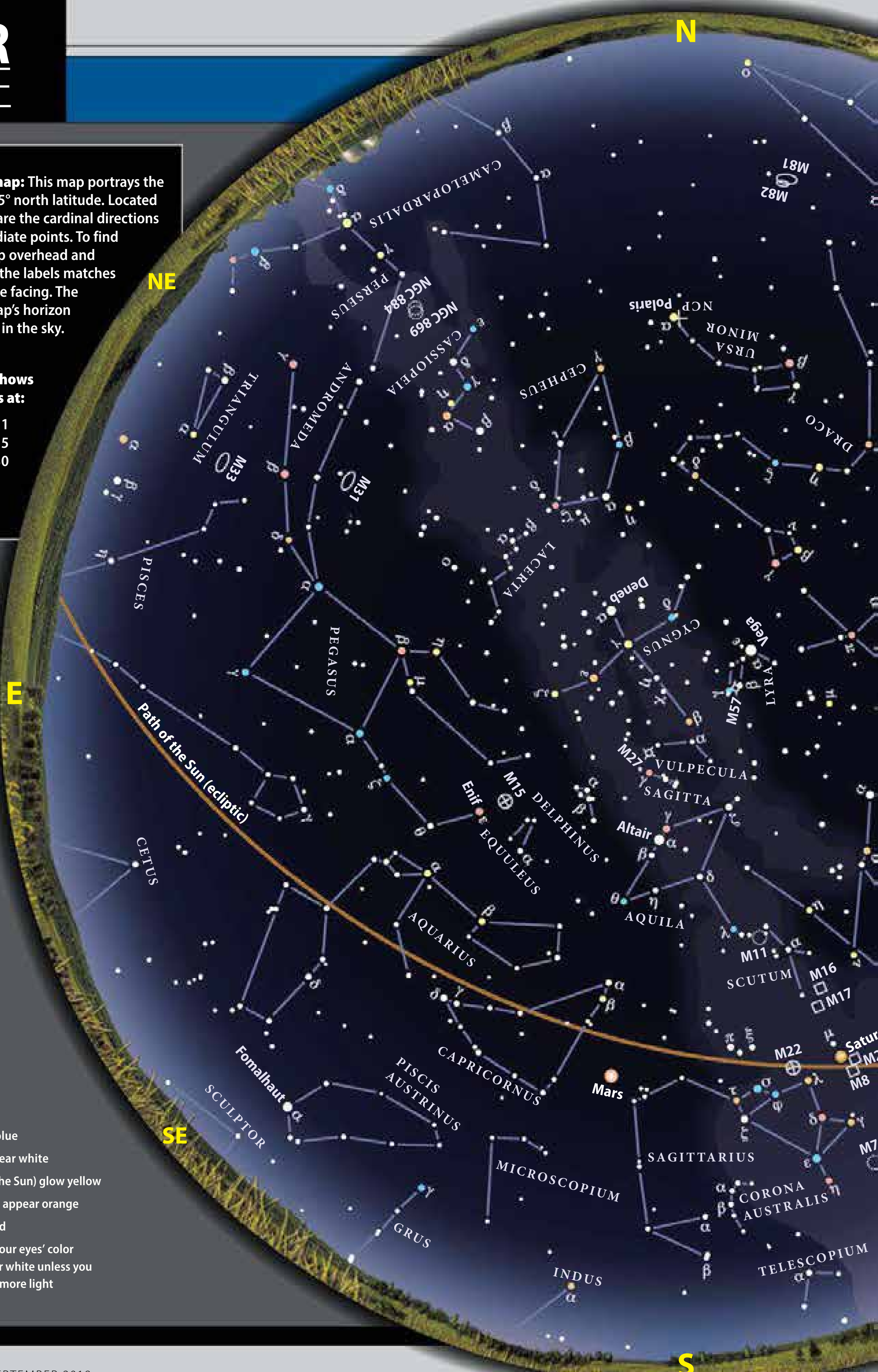
STAR DOME

How to use this map: This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

10 P.M. September 1
9 P.M. September 15
8 P.M. September 30

Planets are shown at midmonth



STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

SEPTEMBER 2018

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

Calendar of events

2 Venus passes 1.4° south of Spica, 5 A.M. EDT

The Moon passes 1.2° north of Aldebaran, 10 P.M. EDT

Last Quarter Moon occurs at 10:37 P.M. EDT

5 Mercury passes 1.0° north of Regulus, 7 P.M. EDT

6 Saturn is stationary, 6 A.M. EDT

7 Neptune is at opposition, 2 P.M. EDT

The Moon is at perigee (224,533 miles from Earth), 9:20 P.M. EDT

9 New Moon occurs at 2:01 P.M. EDT

12 The Moon passes 10° north of Venus, noon EDT

13 The Moon passes 4° north of Jupiter, 10 P.M. EDT

16 Mars is at perihelion (128.4 million miles from the Sun), 9 A.M. EDT

First Quarter Moon occurs at 7:15 P.M. EDT

17 The Moon passes 2° north of Saturn, noon EDT

18 Asteroid Urania is at opposition, 10 P.M. EDT

19 The Moon is at apogee (251,578 miles from Earth), 8:53 P.M. EDT

20 The Moon passes 5° north of Mars, 3 A.M. EDT

Mercury is in superior conjunction, 10 P.M. EDT

SPECIAL OBSERVING DATE

21 Venus gleams at magnitude –4.8 today, the brightest it gets during this evening apparition.

22 Autumnal equinox occurs at 9:54 P.M. EDT

23 The Moon passes 2° south of Neptune, noon EDT

24 Full Moon occurs at 10:52 P.M. EDT

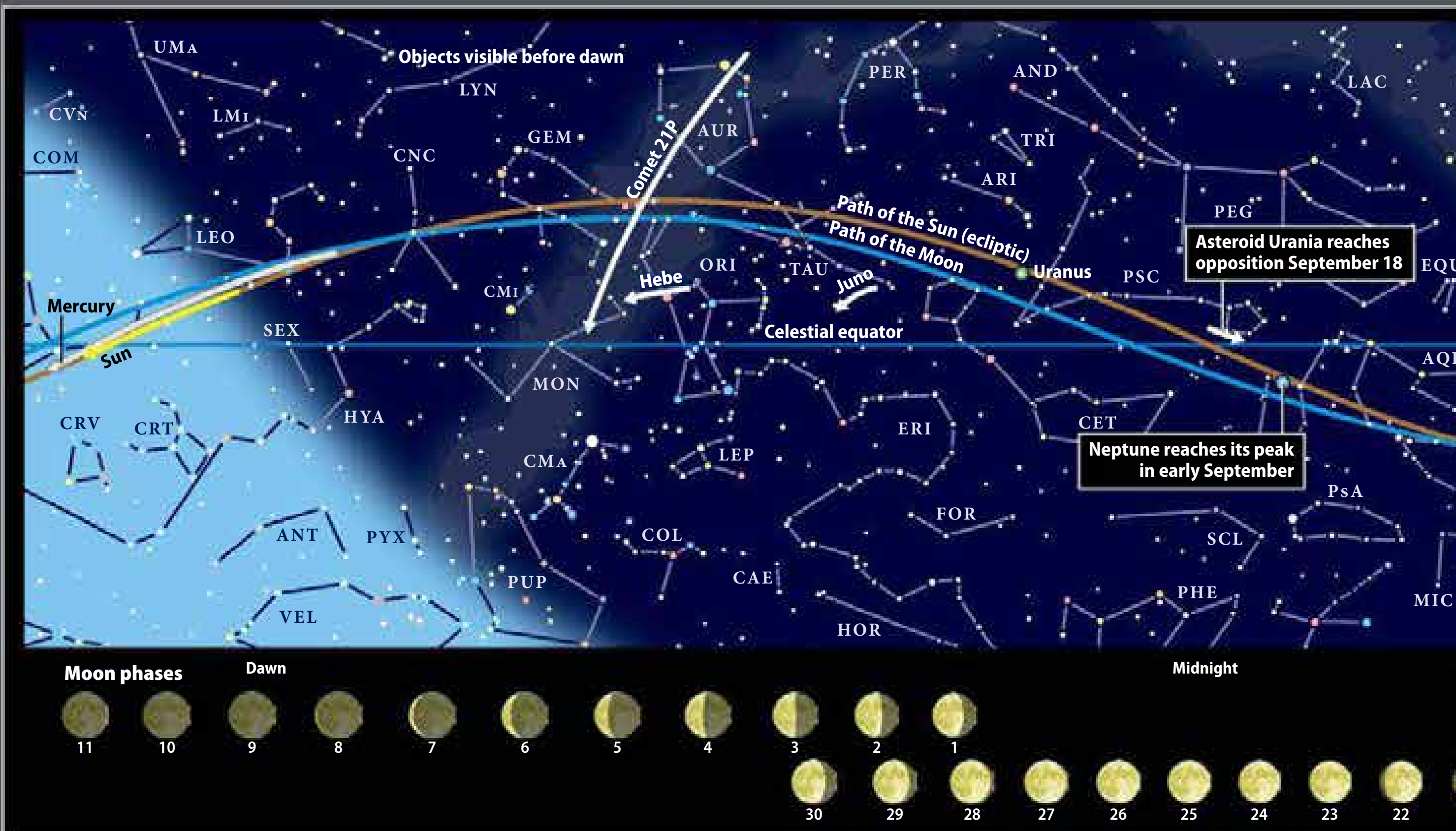
27 The Moon passes 5° south of Uranus, 3 A.M. EDT

30 Pluto is stationary, noon EDT

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**

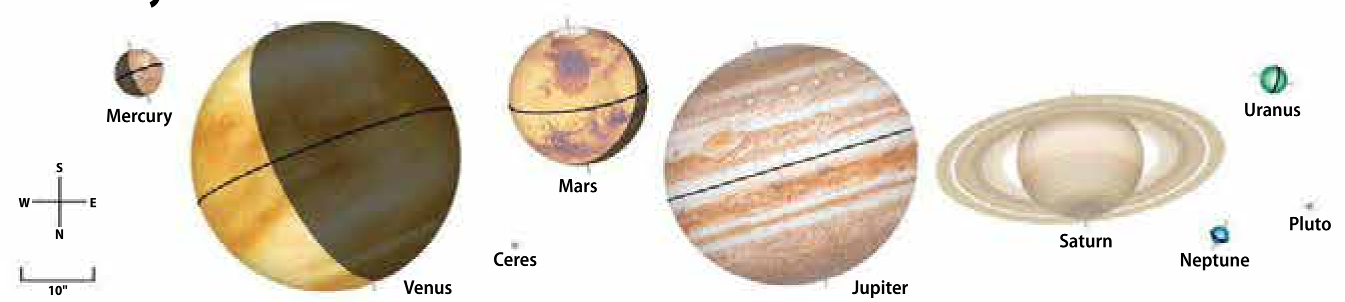
PATH OF THE PLANETS

The planets in September 2018



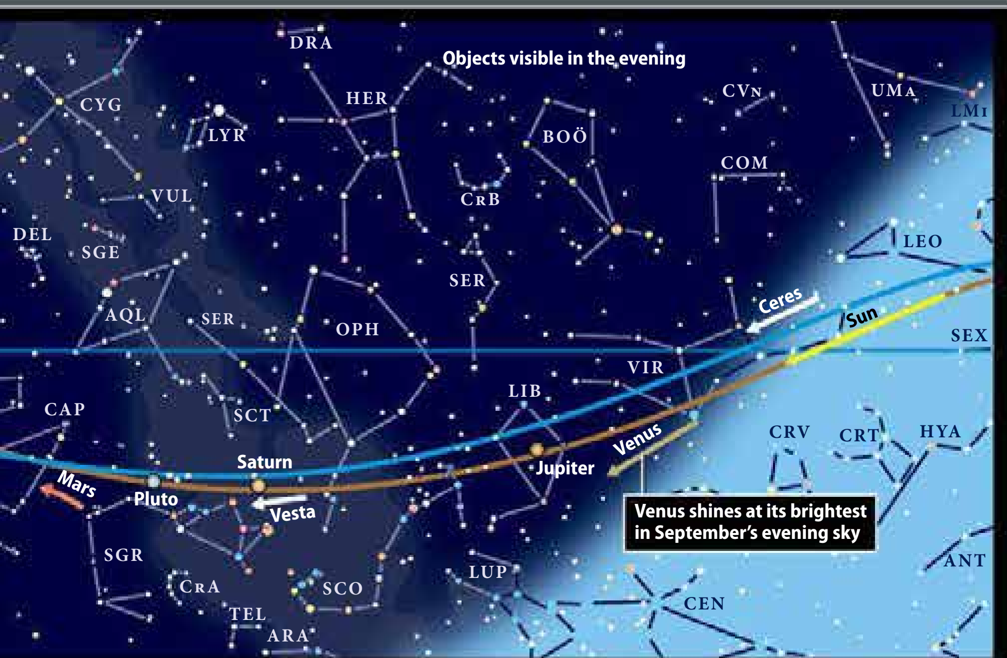
The planets in the sky

These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



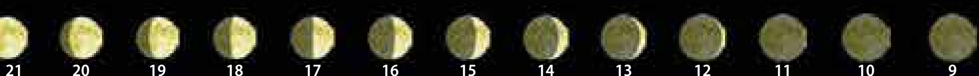
Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	Sept. 1	Sept. 15	Sept. 15	Sept. 15	Sept. 15	Sept. 15	Sept. 15	Sept. 15	Sept. 15
Magnitude	–0.8	–4.7	–1.7	8.6	–1.9	0.4	5.7	7.8	14.2
Angular size	6.4"	35.7"	18.4"	0.4"	33.7"	16.9"	3.7"	2.4"	0.1"
Illumination	65%	31%	91%	100%	99%	100%	100%	100%	100%
Distance (AU) from Earth	1.056	0.467	0.509	3.555	5.858	9.832	19.092	28.943	33.178
Distance (AU) from Sun	0.308	0.728	1.381	2.590	5.380	10.064	19.874	29.940	33.642
Right ascension (2000.0)	9h35.8m	13h57.9m	20h15.7m	12h25.2m	15h07.2m	18h10.2m	1h59.0m	23h04.9m	19h20.4m
Declination (2000.0)	15°04'	–17°21'	–24°45'	5°16'	–16°42'	–22°44'	11°33'	–6°59'	–22°05'

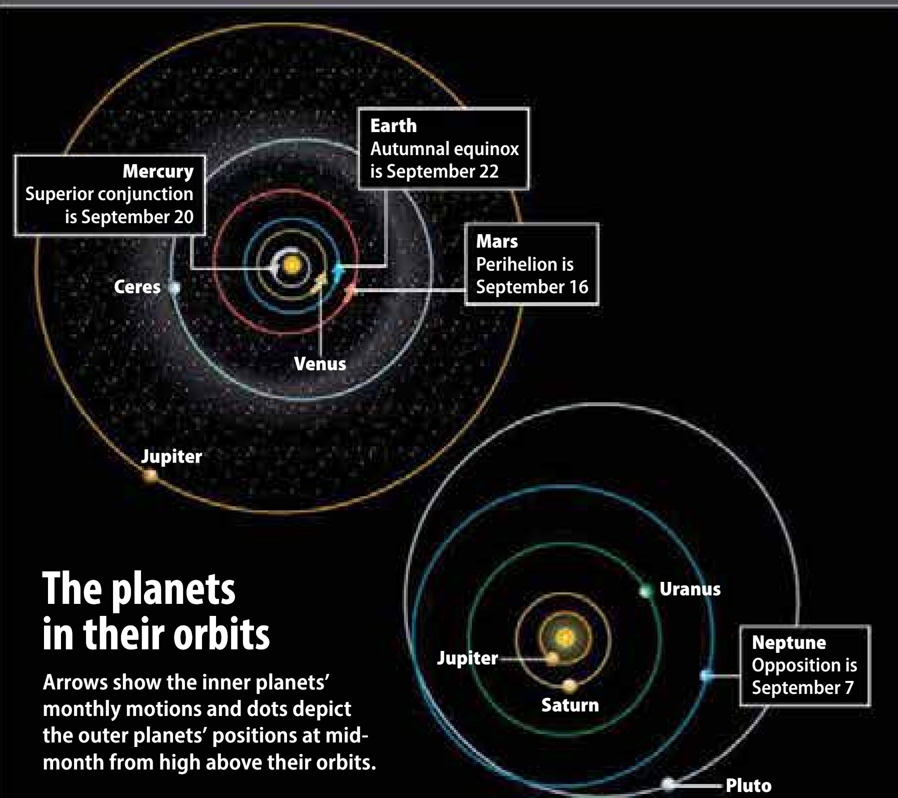
This map unfolds the entire night sky from sunset (at right) until sunrise (at left).
Arrows and colored dots show motions and locations of solar system objects during the month.



Early evening

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.
Note: Moons vary in size due to the distance from Earth and are shown at 0h Universal Time.



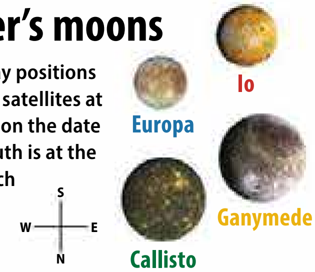


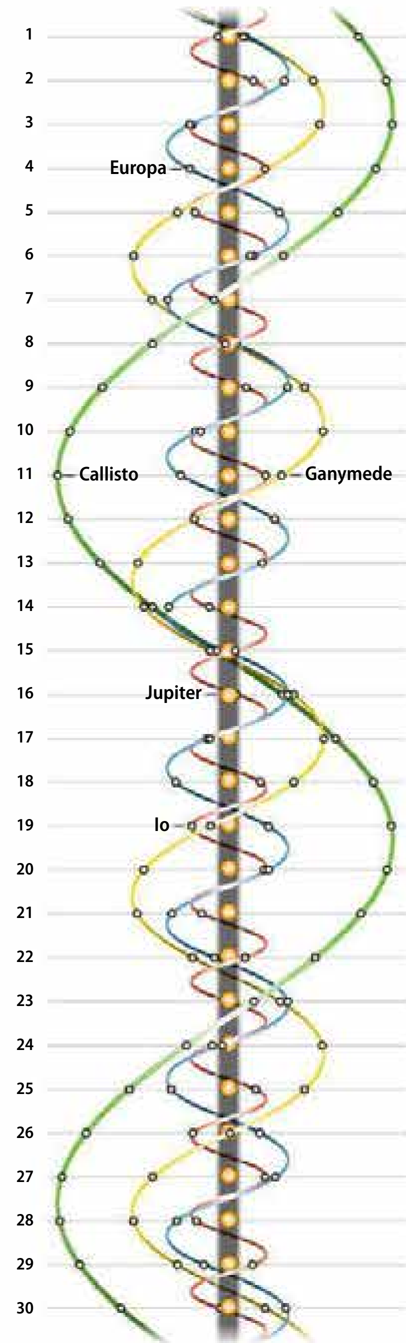
The planets in their orbits

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at mid-month from high above their orbits.

Jupiter's moons

Dots display positions of Galilean satellites at 11 P.M. EDT on the date shown. South is at the top to match the view through a telescope.





ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

— *Continued from page 37*

WHEN TO VIEW THE PLANETS

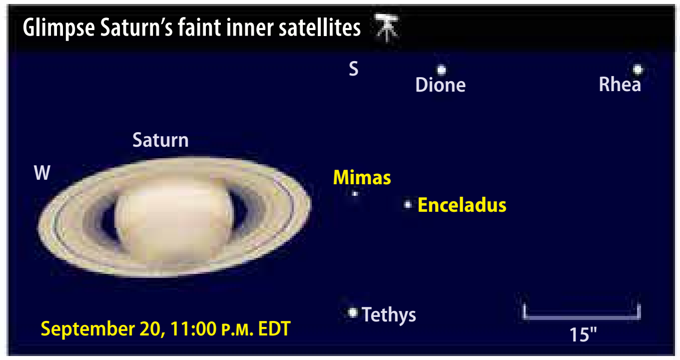
EVENING SKY	MIDNIGHT	MORNING SKY
Venus (southwest)	Mars (southwest)	Mercury (east)
Mars (south)	Saturn (southwest)	Uranus (southwest)
Jupiter (southwest)	Uranus (east)	Neptune (west)
Saturn (south)	Neptune (south)	
Neptune (east)		

above the planet's north pole behind Saturn. Also look for the planet's shadow falling on the eastern side of the rings.

The smallest instruments also reveal Saturn's largest moon, 8th-magnitude Titan. A 4-inch scope brings in four 10th-magnitude satellites. Tethys, Dione, and Rhea, which orbit Saturn at less than half Titan's distance, are the easiest targets. And with periods ranging from 1.9 to 4.5 days, these three provide a constantly changing show.

Iapetus also glows at 10th magnitude at the start of September, when it lies 8.4' west of Saturn. This large distance makes it somewhat harder to spot, but it doesn't get any easier as Iapetus heads back toward the planet because it fades as it goes. The outer moon glows at 11th magnitude when it passes 1.7' north of Saturn on the 18th, and continues to dim as it moves east of the gas giant.

Two inner moons — 12th-magnitude Enceladus and 13th-magnitude Mimas — show up through 8-inch scopes when they lie farthest from Saturn. Try to find them September 20, when they reach greatest eastern elongation within an hour of each other. The two stand just beyond the rings' edge halfway between Dione and Tethys.



Observers have a great chance to track down Mimas and Enceladus when they lie farthest east of the ringed world.

The fourth naked-eye evening planet lies in the south-southeast after sunset. **Mars** shines at magnitude –2.1 September 1, making it the second brightest of our planetary quartet, but it stands out just as much for its stunning orange color. The Red Planet then sits on the border between Sagittarius and Capricornus. Binoculars reveal globular star cluster M75 just 4° to its north.

As September progresses, Mars treks northeastward against the Sea Goat's background stars. It also retreats from Earth and, as a result, its diameter shrinks from 21" to 16" during the month, and it fades about 0.2 magnitude per week. The best times to view it through a telescope come when it lies due south and at peak altitude. In early September, this occurs around 10:30 P.M. local daylight time. Late in the month, it appears highest at 9 P.M.

During moments of good seeing, Mars resolves into a patchwork of dark and bright markings. From North America, evening views in early September show the dark region Mare Sirenum on the central meridian, the line joining the planet's north

COMETSEARCH

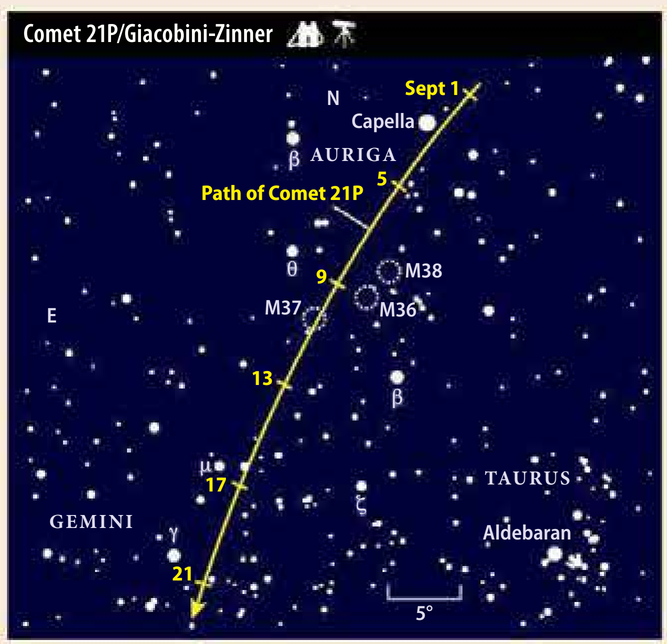
A periodic comet's triumphant return

Since its discovery in 1900, Comet 21P/Giacobini-Zinner has returned to the inner solar system every 6.6 years. Some visits are better than others, however. The comet makes its closest approach to both the Sun and Earth during September's second week, which should push this performance to its second best ever.

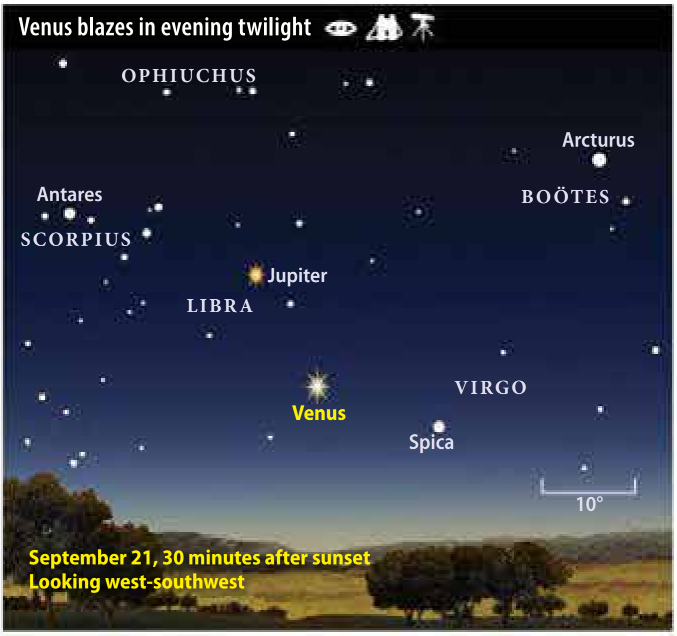
Astronomers expect 21P to peak at 6th or 7th magnitude. But the comet's proximity to Earth means that it will be a diffuse, low-surface-brightness object, so you'll want to view it from a dark-sky site. Although its host constellation, Auriga, rises in the evening, wait until it climbs high in the sky before dawn.

Start at low power to capture the entire coma and most of its bluish gas tail, which should extend 1° or more to the west. Push your scope around a bit to activate the motion-sensitive rods of your eye's peripheral vision. Then try medium magnification to see more detail. The coma's eastern side, where the solar wind pushes ionized gas away, should appear sharpest.

Giacobini-Zinner lies within 2° of magnitude 0.1 Capella on September 2 and 3. Imagers will want to target it a week later at New Moon, when it passes through a photogenic region of the winter Milky Way that includes the star clusters M36 and M38.



This visitor could hit 6th magnitude as it makes its closest approach to the Sun and Earth while passing through the winter Milky Way in Auriga.



This dazzling planet peaks in brightness (magnitude –4.8) in September's second half, when it pairs nicely with its solar system sibling Jupiter.

and south poles that passes through the center of the disk. By the end of the first week, the dark feature Solis Lacus takes center stage. At the same time, Olympus Mons appears on the planet's morning terminator. This is the time to watch for bright clouds that often appear around this huge volcano. In September's second week, the dark sands of Mare Erythraeum take center stage.

Syrtis Major, the darkest feature on Mars, lies near the martian central meridian from around September 20–25. The bright Hellas Basin, the planet's lowest-lying region, sits just south of Syrtis Major. And by month's end, the dark, fingerlike extension of Mare Cimmerium appears at the center of the disk.

Once you've viewed the bright evening planets, turn your attention to their fainter siblings. **Neptune** reaches the peak of its yearly appearance when it comes to opposition September 7. It then lies opposite the Sun in our sky, rising at sunset and climbing halfway to the zenith in the southern sky around 1 A.M. local daylight time.

Neptune glows at magnitude 7.8, so you'll need binoculars or a telescope to see it. It lies 2.2° west-southwest of 4th-magnitude Phi (ϕ) Aquarii on September 1 and 2.9° away from this star on the 30th. A telescope at medium magnification reveals the planet's 2.4"-diameter disk and blue-gray color.

Uranus rises around 9:30 P.M. local daylight time as September begins, and some two hours earlier by month's close. It stands well clear of the eastern horizon just a couple of hours later. The ice giant world resides in southwestern Aries, 12° south of the Ram's brightest star, 2nd-magnitude Alpha (α) Arietis.

At magnitude 5.7, Uranus appears bright enough to see with the naked eye from a dark site, though binoculars make the task easier. Only a few background stars in the area glow as brightly as the planet. To confirm a sighting, point your telescope at the suspected planet. Only Uranus shows a disk, which spans 3.7", with a distinctive blue-green color.

As dawn approaches in early September, **Mercury** appears low in the east. The innermost planet rises nearly 90 minutes before the Sun on September 1 and stands 10° high a half-hour before sunup. It shines at magnitude –0.8 and should be easy to spot against the twilight glow. A telescope reveals the planet's 6"-diameter disk, which appears two-thirds lit.

Mercury drops lower with each passing day but grows brighter as it descends. Look for it through binoculars September 5 and 6, when it passes within 1.5° of 1st-magnitude Regulus. The pair lies about 7° high 30 minutes before sunrise.

__Martin Ratcliffe__ provides planetarium development for Sky-Skan, Inc., from his home in Wichita, Kansas. Meteorologist __Alister Ling__ works for Environment Canada in Edmonton, Alberta.

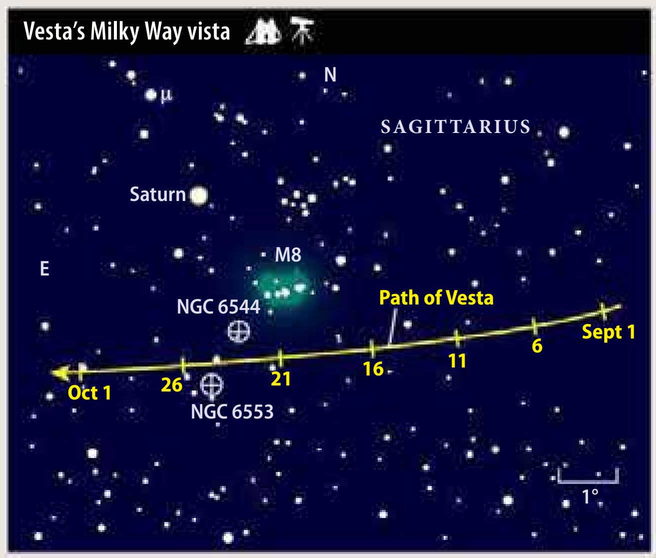
LOCATING **ASTEROIDS**

Sailing past the Lagoon Nebula

September's typically great weather likely will give you a string of clear nights to follow asteroid 4 Vesta passing near the Milky Way's center in Sagittarius. From the suburbs, start at the yellow beacon Saturn and make the short hop to this main belt asteroid. Under a dark sky, begin at the sprawling Lagoon Nebula (M8) and shift to the position indicated on the chart below.

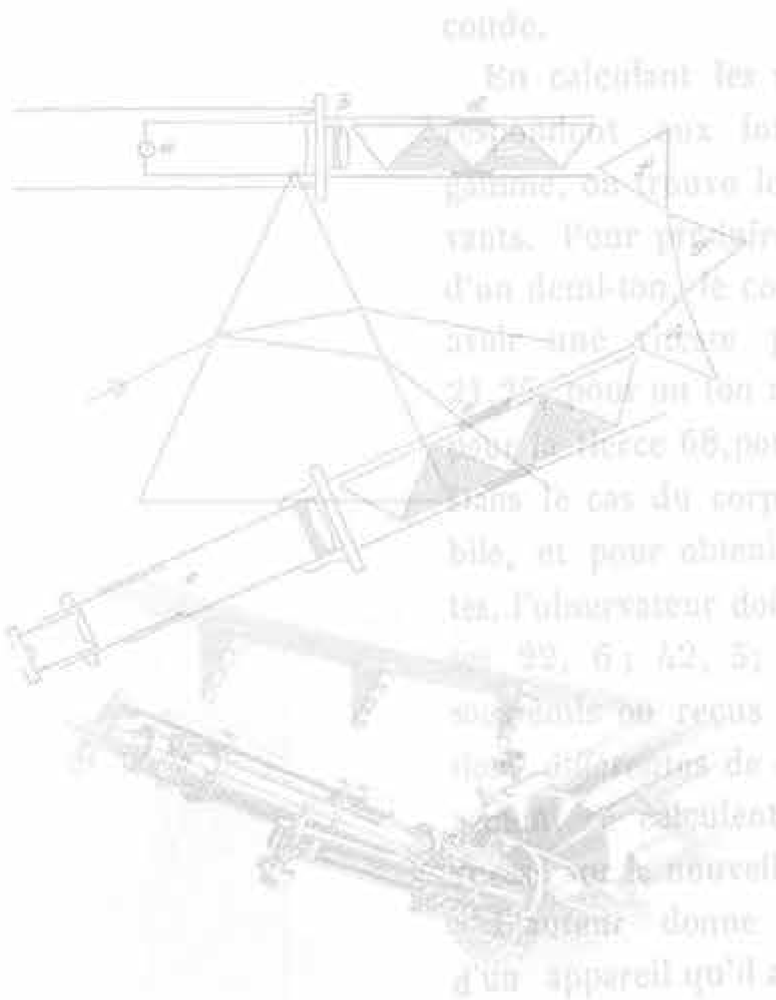
No matter your observing site, the first thing you'll notice in early September is the scarcity of background stars, which allows Vesta to stand out a bit more. Interstellar dust in our galaxy's disk obscures much of our view. Until mid-September, 7th-magnitude Vesta is the brightest object in the field.

Once the asteroid passes south of the Lagoon around the 21st, you might confuse several stars for the space rock. Make a sketch of the field that includes the four or five brightest dots, then return a night or two later to confirm which "star" moved. You can also take advantage of Vesta's proximity to track down globular star clusters NGC 6544 and NGC 6553. Through a 6-inch scope, they'll look like slightly fuzzy, 8th-magnitude stars.



The sky's brightest asteroid slides south of the Lagoon Nebula (M8) and between two 8th-magnitude globular clusters after midmonth.

GET DAILY UPDATES ON YOUR NIGHT SKY AT **www.Astronomy.com/skythisweek.**



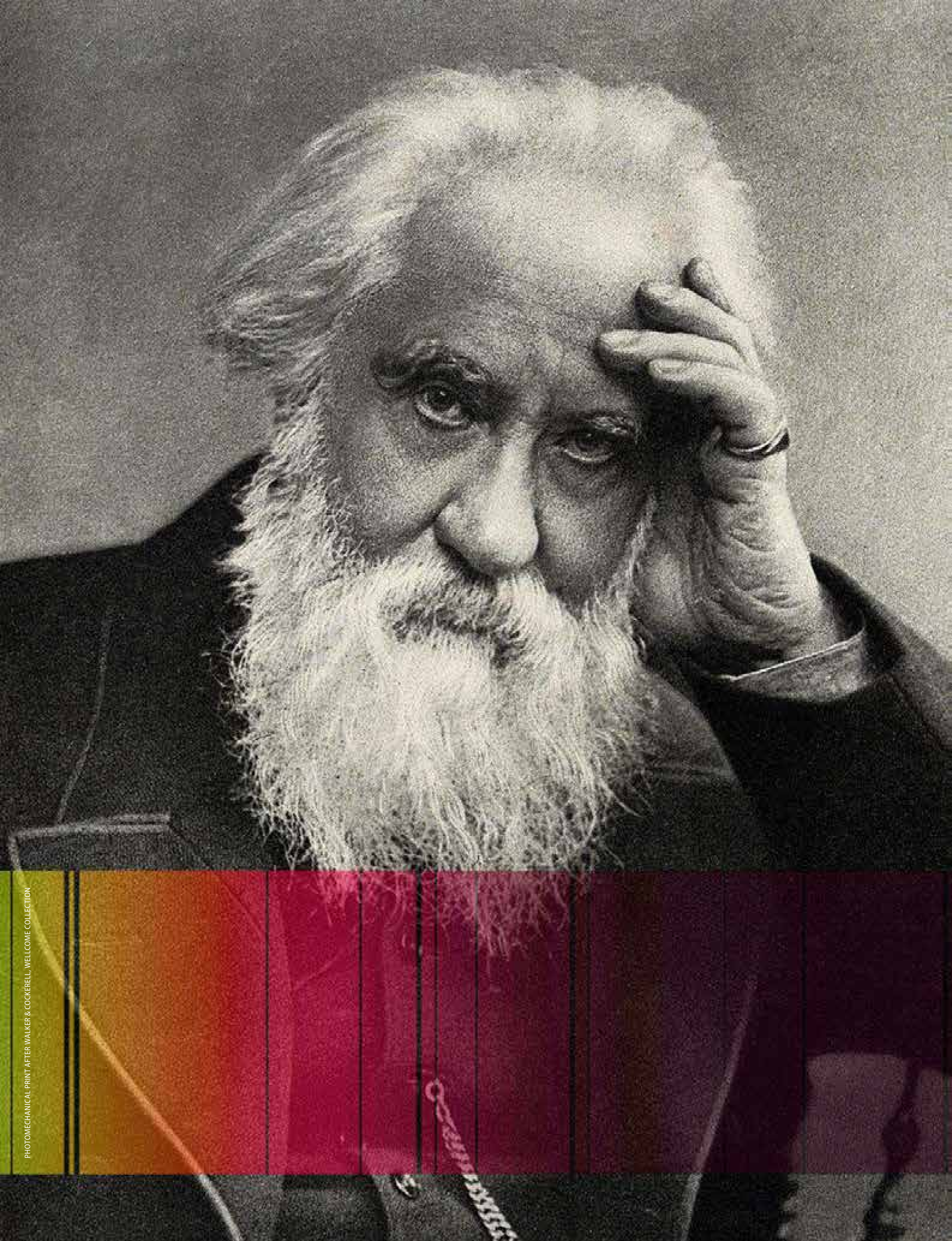
How William Huggins shaped astrophysics

In 1868, an English astronomer pioneered a way to measure the motion of stars and other objects. **by Barbara J. Becker**

For most of human history, observers envisioned the night sky as a sphere studded with fixed stars. It is easy to understand why. Our lives are too short and our unaided senses too limited to detect any stellar motion. In 1718, Edmond Halley discerned the "particular motion" of three stars across the sky based on careful comparison of ancient and contemporary star maps. But stars offer none of the usual cues we might use to tell if they also moved along our line of sight.

That changed in 1868 when English astronomer William Huggins applied the spectroscope and Doppler's principle to the problem. The impact on the theory and practice of astronomy was revolutionary. Within a generation, the questions astronomers could ask about the bodies they observed and the methods deemed appropriate to examine them changed in ways their predecessors could not have imagined.

Huggins' name might be unfamiliar to modern ears, but the self-taught amateur astronomer was celebrated in his own lifetime as the father of astrophysics. Born in 1824, he sold his family's London silk shop at the age of 30 to devote himself full time to his growing interest in astronomy. In 1856, he built a substantial observatory attached to his home and recorded his first observations in a bound notebook. In the early 1860s, he drew widespread acclaim for his pioneering work in celestial spectroscopy, the technique of splitting



PHOTOMECHANICAL PRINT AFTER WALKER & COCKERELL. WELLCOME COLLECTION

Sir William Huggins' contemporaries, left to right: William Allen Miller, Christian Doppler, and James Clerk Maxwell. LOVELL REEVE; UNKNOWN (PUBLIC DOMAIN); ENGRAVING BY G.J. STODART FROM A PHOTOGRAPH BY FERGUS OF GREENOCK

starlight into its constituent wavelengths. (For the details of this process, see "How does spectroscopy work?" on p. 47.) Huggins was among the first to compare stellar spectra directly with those of terrestrial elements, the first to observe emission lines in the spectra of nebulae, and the first to observe a nova's spectrum.

At that time, members of the professional astronomical community saw the spectroscope's celestial discoveries only as interesting distractions from the real task at hand, namely mapping the sky with precision to aid in terrestrial navigation and testing Newton's laws. All this changed after Huggins introduced spectral analysis as a tool to detect and measure the motion of celestial bodies in three-dimensional space.

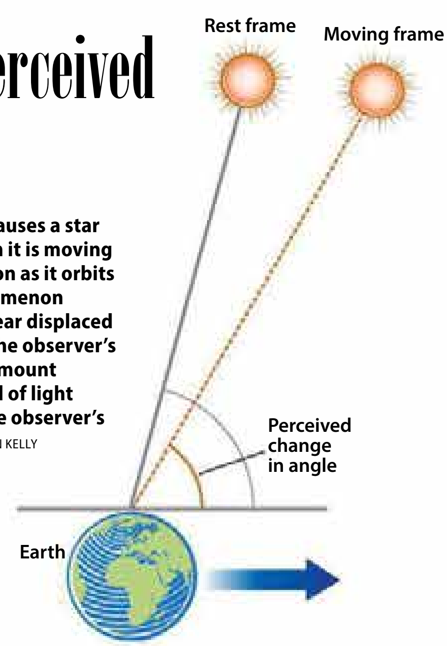
SOLVING STAR COLORS

To understand how Huggins was drawn to this line of investigation, we need to start with the enigma of star color. This characteristic had long intrigued observers. Did a star's color have a real physical or chemical cause, was it more a matter of unavoidable instrumental distortion, or was it due to illusory individual perception? With no obvious means to resolve the issue with any certainty, it seemed that it might always remain a matter of creative speculation.

In 1844, English astronomer William Henry Smyth urged astronomers to methodically observe double star systems like Albireo (Beta [β] Cygni), which exhibit different, sometimes complementary colors. Jesuit astronomer Benedict Sestini took up Smyth's challenge, and in 1850 he published a paper suggesting "variations in color may be owing to variations in stellar velocity." Smyth expressed cautious interest in what he called "Sestini's theory," unaware that an explanation for star color had already been introduced nearly a decade earlier by Austrian mathematics professor Christian Doppler.

Few people had heard of Doppler's name or his work. His lack of notoriety was hardly surprising: When he presented his theory before the Royal Bohemian Society of Sciences in May 1842, only a handful of members were present. Doppler considered his theory as an extension to stellar aberration, the small annual shift in a star's apparent position on the sky. While aberration is a natural consequence of both the finite speed of light and Earth's orbital motion around the Sun in a plane perpendicular to a star's incoming light, Doppler believed he had discovered something analogous resulting from motion parallel to its incoming light.

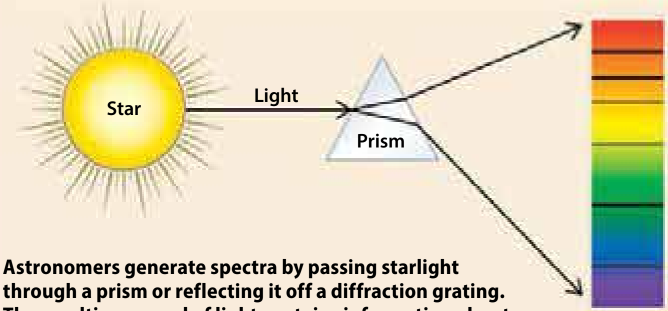
Stars' perceived motions



Stellar aberration causes a star to appear as though it is moving due to Earth's motion as it orbits the Sun. This phenomenon makes the star appear displaced in the direction of the observer's motion by a small amount related to the speed of light and the speed of the observer's motion. *ASTRONOMY*: ROEN KELLY

The two brightest stars in the Albireo system, easily resolvable through a small telescope, appear complementary in color. One shines yellow-orange, while its partner appears blue. Astronomers once wondered whether these colors resulted from compositional differences, stellar motion, or even observer bias. HENRYK KOWALEWSKI

HOW DOES SPECTROSCOPY WORK?



Astronomers generate spectra by passing starlight through a prism or reflecting it off a diffraction grating. The resulting spread of light contains information about the source's composition and motion. *ASTRONOMY*: ROEN KELLY

A spectroscope (for visual study) or spectrograph (for photography) separates incoming light, such as starlight, into its constituent wavelengths using either a prism or a diffraction grating, both of which spread light out by wavelength. The result is called a spectrum.

Atoms absorb or emit light of specific wavelengths that correspond to the differences between the energy levels where electrons reside. Absorption occurs when a photon, a particle of light, strikes an electron and provides the energy to boost it to a higher energy level. Emission occurs when the electron falls back down to a lower energy state, releasing a photon of the same energy. Absorption lines appear dark while emission lines appear bright. Each element and molecule produces a unique set of lines that can be used to identify its presence in a given spectrum.

If the source is moving, its spectral lines — as a set — will shift either toward the red (motion away from the observer) or blue (motion toward the observer) end of the spectrum due to the Doppler effect. All the lines shift by the same amount, so the spacing between lines relative to each other does not change.

During spectroscopy, researchers first create a reference spectrum produced by a known source, such as a single element like hydrogen, to calibrate the instrument. It also provides a reference point for any shifting of spectral lines due to motion. —*Alison Klesman*

Doppler was not an experimentalist. He based his theory on the mathematics of wave behavior, which describes how an observer's perception of frequency will change if the wave source and the observer move toward or away from one another. Doppler pointed out that any detectable difference between a wave's intrinsic frequency and the frequency perceived by an observer will make it possible to calculate the source's relative speed of approach or recession. He applied this principle first to sound and then to light waves, claiming it could account for many previously unexplained astronomical phenomena, such as the colors observed in binary stars, as well as changes reported in the color and brightness of periodic variable stars and novae.

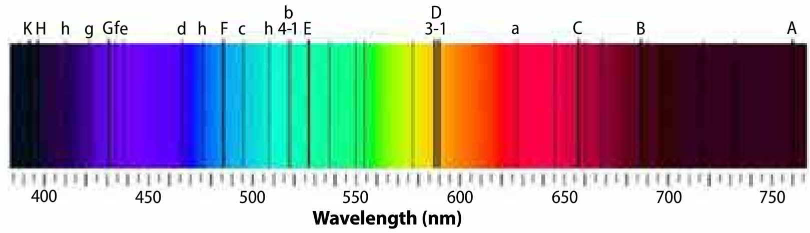
In June 1845, Dutch meteorologist Christoph Hendrik Diedrik Buijs-Ballot devised a grand experiment to test Doppler's ideas. During several trials, groups of musicians and musically trained observers switched roles as passengers on and bystanders alongside a noisy moving railway train. While the musicians struggled to sustain a steady monotone, the observers reported what they heard. Despite the tremendous challenge of executing these trials, Buijs-Ballot believed the reported changes in pitch matched Doppler's predictions.

However, Buijs-Ballot was less sure about extending the theory to stars. The speed of light is nearly a million times faster than that of sound. He doubted any star moved fast enough for an observer to perceive a measurable difference in its appearance. Even if such a speedy star were found, he pointed out that Doppler was wrong to expect its motion to produce any hint of color. Buijs-Ballot assumed that any wavelengths that shifted out of the visible range at one end of the spectrum would simply be replaced by previously invisible rays shifted into it at the other end.

Buijs-Ballot was not the only one studying the effect of motion on sound. In an 1848 lecture, French physicist Armand Hippolyte Louis Fizeau announced his own conclusions on how the motion of a sound's source affects what an observer hears. Fizeau was unaware of Doppler's and Buijs-Ballot's work, giving him a fresh perspective on

how his acoustic experiments might apply to light. He felt sure that stars could and did move fast enough to change the perceived frequency of their emitted light. And although Fizeau doubted such a change would affect a star's overall color, he suggested it could be detected spectroscopically, thanks to the dark lines Joseph von Fraunhofer had mapped in solar and stellar spectra. He proposed using these lines as benchmarks, like the monotones he had relied on to hear a shift in pitch during his acoustic experiments. Fizeau was optimistic that astronomers could and would develop instruments that could precisely measure such displacements.

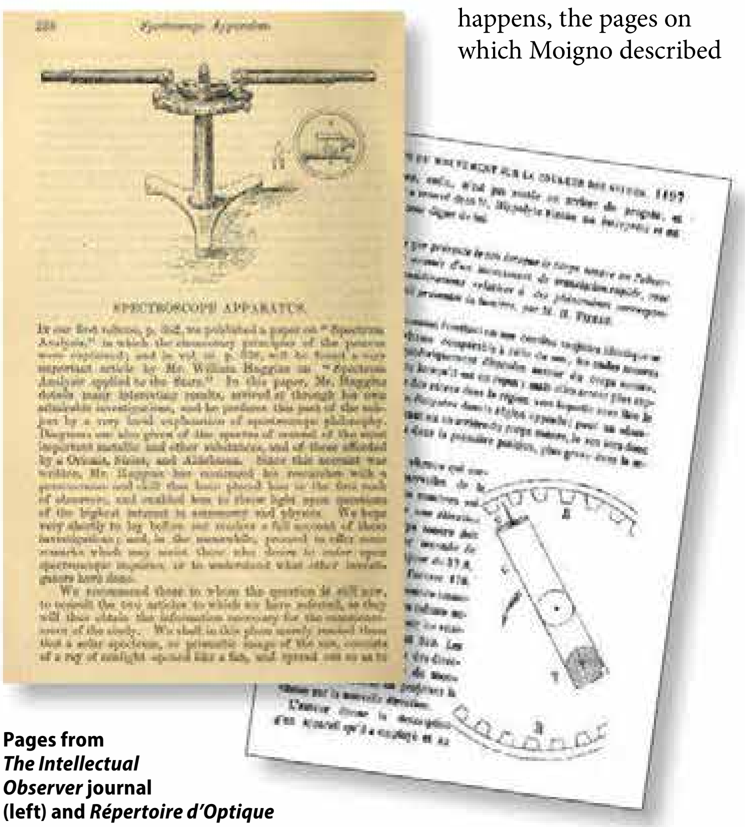
The Fraunhofer lines



In 1802, William Hyde Wollaston observed dark lines in the Sun's spectrum. Joseph von Fraunhofer, for whom the lines are named, plotted more than 500 of these lines beginning in 1814. The brightest are denoted by the letters A through G; these dark lines represent absorption of light by elements in the Sun's atmosphere. Similar absorption lines appear in the spectra of other stars. SAPERAUD (WIKIPEDIA)/CEPHEIDEN (WIKIPEDIA)

MORE QUESTIONS THAN ANSWERS

In 1850, a detailed summary of Fizeau's 1848 lecture was included in a review of Doppler's theory in *Répertoire d'Optique Moderne*, published by French physicist Abbé Moigno. Physicist James Clerk Maxwell often consulted the *Répertoire*; in 1857, he turned to this valued resource to read up on Fizeau's efforts to measure the speed of light in different media. As it happens, the pages on which Moigno described those experiments immediately preceded his review of Doppler's work.



Pages from *The Intellectual Observer* journal (left) and *Répertoire d'Optique Moderne* by Abbé Moigno review information about spectroscopes and Doppler's theory.
HARVARD UNIVERSITY, MUSEUM OF COMPARATIVE ZOOLOGY, ERNST MAYR LIBRARY; GOOGLE

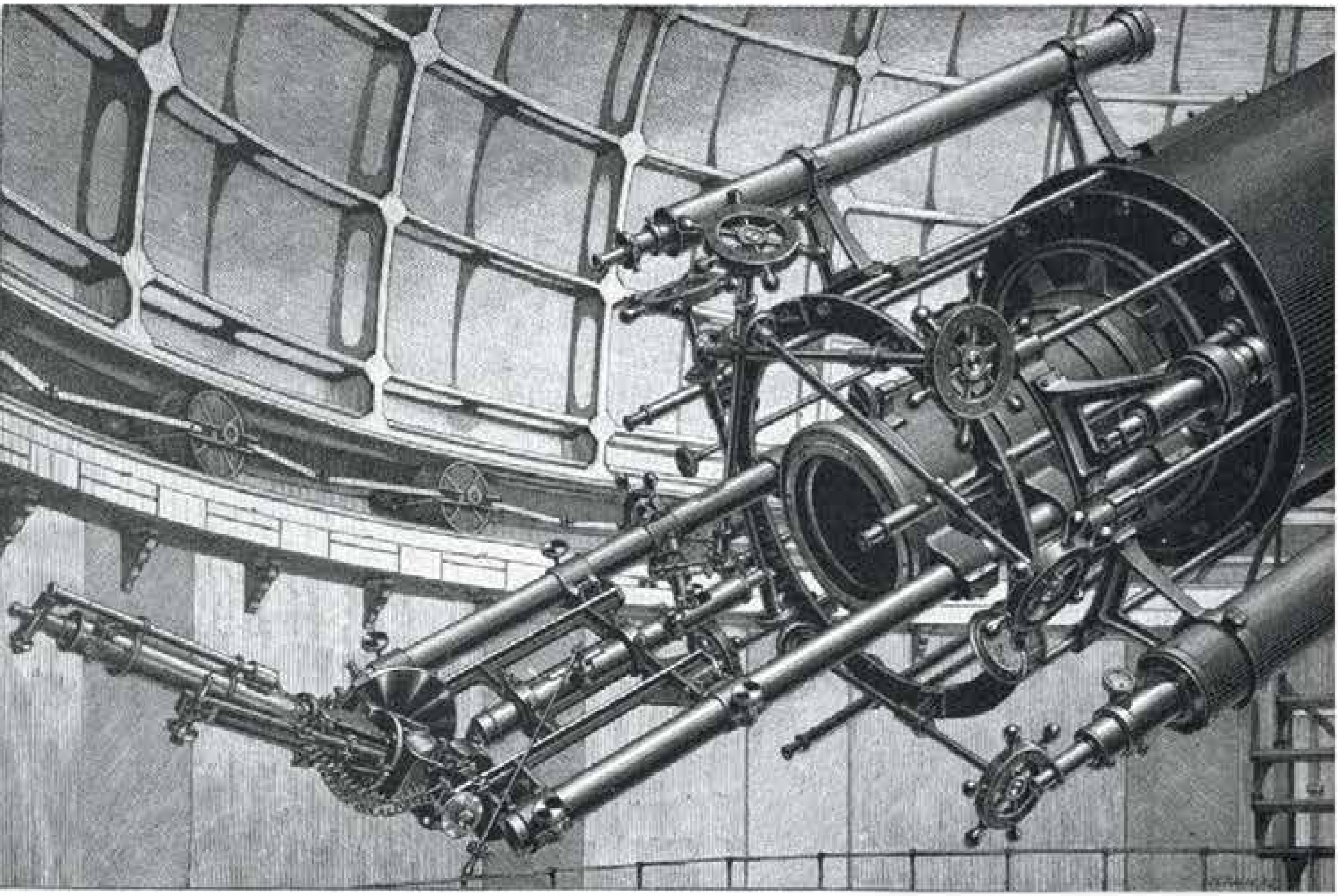
So, it is hard to imagine that Maxwell was unaware of either Doppler's ideas or Fizeau's 1848 lecture by the time he attended a Royal Society meeting on May 26, 1864. At this meeting, Huggins and chemist William Allen Miller read their first joint paper, "On the Spectra of Some of the Fixed Stars," confirming that star spectra are interrupted by an assortment of dark lines.

Their results must have resonated with Maxwell's thoughts that evening. Inspired by Fizeau's experiments, he had recently tried to detect Earth's motion through the luminiferous ether, an omnipresent medium once proposed to explain light's propagation through empty space. So with dark lines and Fizeau very much on his mind, Maxwell would have listened with keen interest as Huggins and Miller introduced their groundbreaking work on stellar spectroscopy.

In his account of the meeting for *The Reader*, Norman Lockyer, the magazine's science editor, reported that the two collaborators presented "pretty certain proof of the idea which has long been floating in many minds as to the cause of the colours of the stars," namely, that they depend "upon the differences of … their chemical constitution." For Lockyer, this meant "that the colours of the stars must be better watched than they have been," and that "some other theory than Doppler's must be found to account for their variability."

Maxwell echoed Lockyer's doubts concerning Doppler's theory. Using words that sounded like they had come directly from Fizeau's 1848 lecture, Maxwell is quoted in Lockyer's article stating that "if the colours were really tinged in consequence of the motion either of the star or our earth, the lines in the spectrum of the star would not be coincident with the bands of the metal observed on the earth, which gives rise to them."

Lockyer ultimately declared that "Messrs. Huggins and Miller, doubtless will not let the matter rest." And he



Following Huggins' work showing spectroscopy could be used to chart stellar motion along the line of sight, major observatories began incorporating spectroscopes into their instruments. The Star-Spectroscope at Lick Observatory, shown mounted on the observatory's 36-inch (91 centimeters) refracting telescope, was designed by James Keeler and built by John Brashear. It used prisms and a diffraction grating, allowing astronomers to choose the type of spectrum they wanted to produce. JULIUS SCHEINER

was right, sort of. Nearly four years later, in April 1868, Huggins submitted a paper to the Royal Society, not to introduce a new theory of star color, but to describe a method to detect and measure the relative motion of Earth and stars along the line of sight, based on Doppler's principle.

TESTING THE THEORY

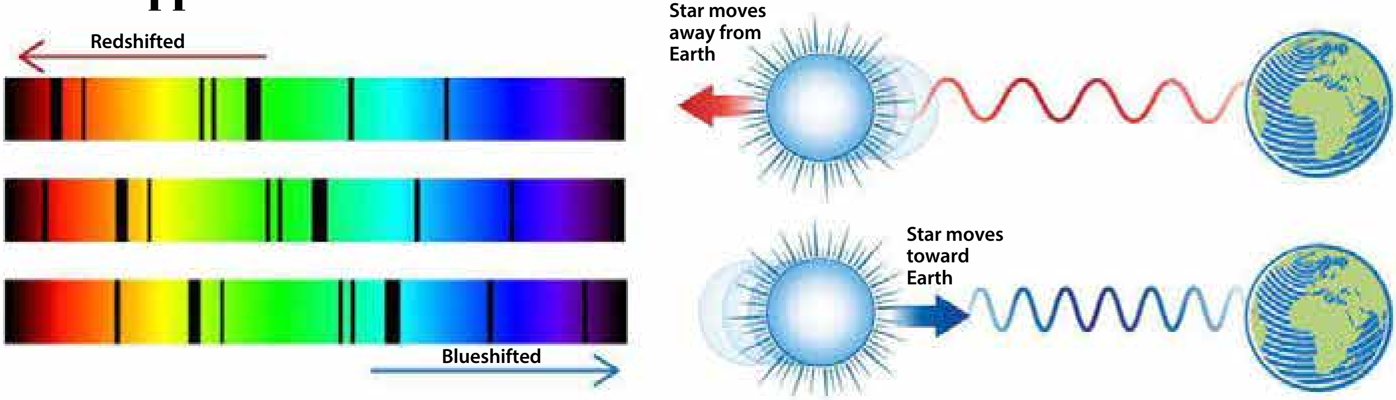
Testing Doppler's controversial ideas on star color and stellar motion may have been a back-burner project for Huggins that came to the fore only after he acquired instruments he believed were up to the demands of such a challenging effort. But that does not explain why he chose to launch the project when he did.

A possible trigger may have been a presentation on star color at the May 1867 meeting of the Royal Astronomical Society by Sidney Bolton Kincaid, a staunch adherent to Smyth's plan to observe and record star colors. Kincaid described a new apparatus he called the Metrochrome. He had developed the device to replace previous methods of describing a star's color in words or by a color illustration that could deteriorate over time. The Metrochrome used an incandescent platinum wire as an artificial star and an array of colored filters made of strictly prescribed chemical solutions as a means "by which the tints of fixed stars may be exactly recorded relatively to standards easily reproducible by any observer, with any kind of telescope, any number of years hence."

Kincaid's talk would have thrilled Huggins. For one thing, the two had collaborated before. And Huggins was fascinated by gizmos. The idea behind the Metrochrome, its ingenious design, and its ease of use would have sparked his creative energies. It also would have refocused his attention on the old star-color question.

Did Kincaid reignite Huggins' interest in star color and Doppler's work? Or was it just a coincidence that

The Doppler effect



The change in the observed wavelengths from a moving source is called the Doppler effect. First observed as a change in the pitch of sound waves, this effect also applies to light emitted by stars. Motion toward the observer causes light to shift toward the blue end of the spectrum, while motion away from the observer causes a shift toward the red. All lines in a star's spectrum shift by an equal amount, and the offset can be measured from a stationary reference spectrum. *ASTRONOMY*: ROEN KELLY

Huggins chose this particular time to seek Maxwell's advice on measuring the motion of stars in the line of sight? Whatever prompted Huggins to reconnect with Maxwell, it was a good move as he prepared to pursue that line of investigation. We can infer from Maxwell's reply that both he and Huggins had given Doppler's ideas some serious thought since May 1864, and had come to view those ideas as key to success in this endeavor.

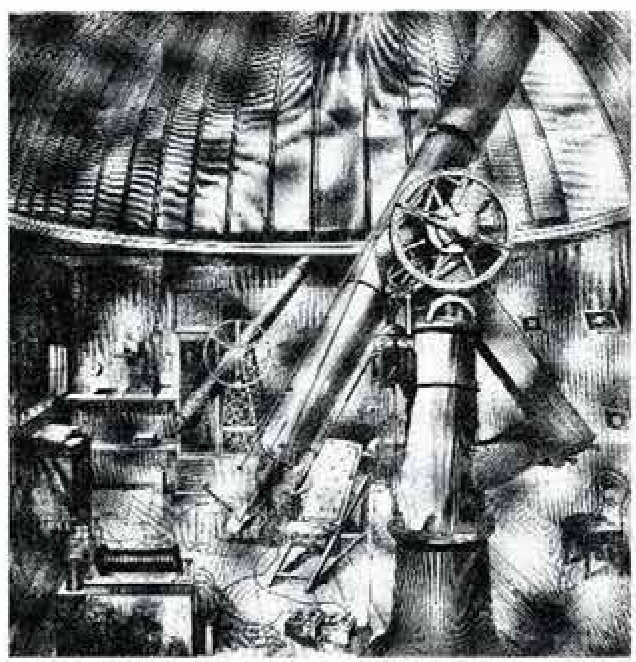
Huggins' original query to Maxwell is lost. An excerpt from the reply he received on June 12, 1867, survives only because Huggins shrewdly included it in his 1868 paper. Maxwell's letter fleshed out the theory and method underpinning Huggins' novel investigation and placed authoritative weight behind his conclusions.

Although Maxwell still drew on Fizeau's 1848 lecture, he now acknowledged that if an individual spectral line of a known terrestrial element could be compared simultaneously with its stellar counterpart, even small differences in its position could be detected with the right instrument. Then, Doppler's formula could be used to calculate the relative motion of the star and Earth along the line of sight.

Huggins had just purchased a new micrometer that he felt met the task's demands for precision. On June 25, 1867, with the Moon at Last Quarter, he eagerly took aim at Arcturus (Alpha [α] Boötis), then perched high overhead in the evening sky. Unfortunately, poor conditions deprived him of "the steady distinction necessary" to detect "any motion towards or away from the earth," he recorded in his observing notes.

Today, measuring stellar radial velocity — mapping tiny shifts in spectral lines to determine the motion of a star relative to an observer — is a straightforward and routine procedure thanks to photography and precision instruments. Keep in mind that Huggins conducted his efforts entirely by eye. His notebook records help us understand how he handled the overwhelming challenges he faced at each step, and they bring into relief his skill in persuading his colleagues that he had, in fact, succeeded.

Armed with a new and more highly dispersive spectroscope, Huggins tried again February 11, 1868, this time taking aim at Sirius (Alpha [α] Canis Majoris). He compared the star's blue Fraunhofer F line, which



This engraving depicts Huggins' observatory around the time he was working on his line-of-sight measurements. The print was created years later, likely based on Huggins' description of his observatory and its setup from memory. ENGRAVING BY JOSEPH SWAIN, PUBLISHED IN *AN ATLAS OF REPRESENTATIVE STELLAR SPECTRA* BY WILLIAM HUGGINS AND MARGARET LINDSAY HUGGINS, 1899

appears due to the presence of hydrogen, with that of a hydrogen spark. He recorded: "Appeared to me very slightly more refrangible than line of [hydrogen]." In other words, Sirius' line appeared shifted toward the blue end of the spectrum.

But on February 24, he found the star's F line to be shifted toward the red!

He designed a better way to compare the star and spark spectra simultaneously, but on March 6, he complained he was unsure of the comparison spectrum's alignment: "Made the observation at least 20 times but without absolute certainty."

On March 10, he cheerfully recorded that he was "almost certain after a great number of trials" that Sirius' F line was shifted toward the red — only to have his confidence shaken two nights later when the star's lines once again appeared to be shifted toward the blue, the opposite of his earlier "very satisfactory" observations.

On March 30, he was relieved to see Sirius' spectrum again shifted toward the red. "Taken in connection with the satisfactory result of [February] 24, it may be considered as certainly confirmatory of the observations on that night. I made numerous comparisons during an hour, almost always the same result."

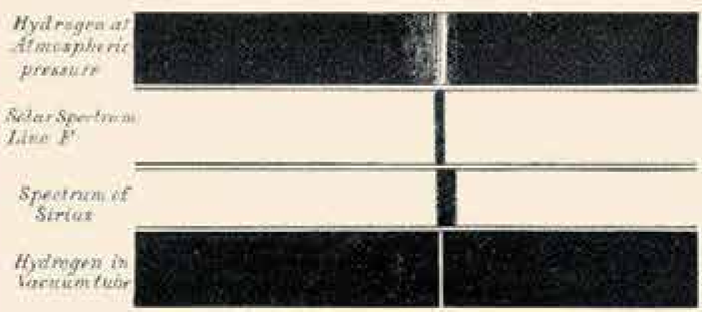
By April 4, with Sirius too low in the sky, Huggins compiled his observations and submitted his paper to the Royal Society on April 23. It was titled "Further Observations on the Spectra of Some of the Stars and Nebulae, with an Attempt to Determine Therefrom Whether These Bodies are Moving towards or from the Earth." Its tone is one of confidence and spirited adventure. He advertised the soundness of his measures and the theoretical foundation for his interpretation of them. He expressed satisfaction that he had resolved his instrumental problems through clever manipulation of instruments and enviable patience.

Huggins does not say how many observations he actually made, or of those, how many were discarded or why. In his view, throwing out those he deemed unworthy was simply judicious weeding conducted to ensure the reliability of his measurements.

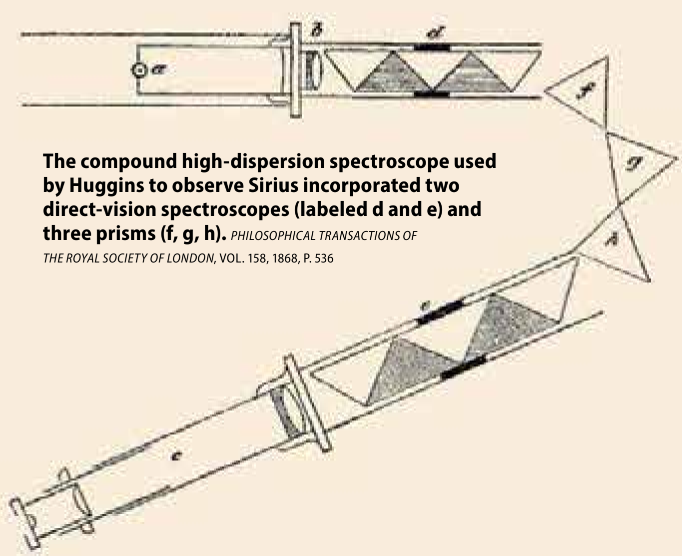
The paper was sent to Astronomer Royal, George Airy, for review. He praised Huggins's detailed account of his instruments and challenges. However, Airy questioned the legitimacy of assuming that the line "at or near F observed in Sirius" was, in fact, due to hydrogen. Airy thought it "illogical" to insist that the line was due to hydrogen because it coincided with the terrestrial hydrogen line, while at the same time arguing that the star was in motion because of its lack of coincidence. Despite these concerns, he pronounced the paper a "very important one," and recommended that it be published in the Royal Society's journal of record, *Philosophical Transactions of the Royal Society*.

Sirius is a hot blue star 8.6 light-years from Earth. It is the brightest star in the sky, making it a tempting target for Huggins to observe using his spectroscope in 1868. AKIRA FUJII/ESA

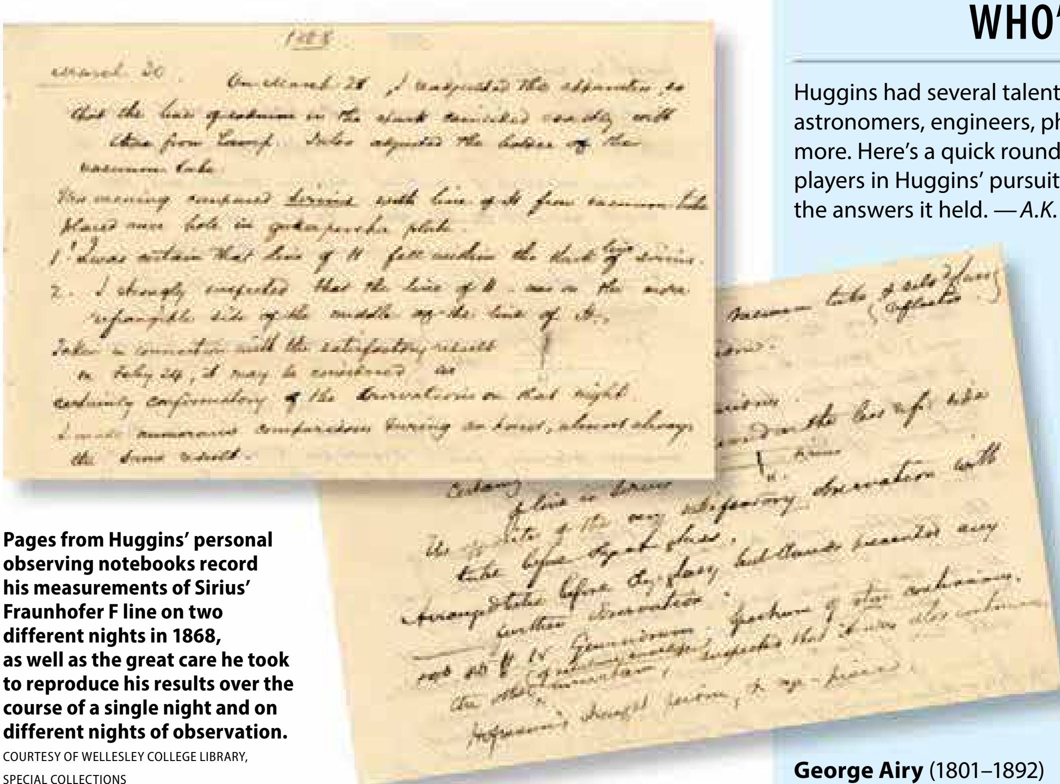
A Sirius subject



Huggins made meticulous observations by eye of the Fraunhofer F line in Sirius' spectrum, comparing it with a hydrogen spark that he used as a reference. He published this diagram in 1868. *PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY OF LONDON*, VOL. 158, 1868, P. 536, PLATE XXXIII



The compound high-dispersion spectroscope used by Huggins to observe Sirius incorporated two direct-vision spectroscopes (labeled d and e) and three prisms (f, g, h). *PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY OF LONDON*, VOL. 158, 1868, P. 536



Pages from Huggins' personal observing notebooks record his measurements of Sirius' Fraunhofer F line on two different nights in 1868, as well as the great care he took to reproduce his results over the course of a single night and on different nights of observation.
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SPECTROSCOPY FINDS ITS PLACE

The physical theory behind Huggins' line-of-sight measures was a challenge to the best of contemporary astronomers. A few years later, Airy wrote to physicist George Stokes: "In some of the German pamphlets now afloat, on optical subjects, there is repeated allusion to *das Doppelsche Princip*, or some such term, conveying the idea that a man named Doppel has introduced some optical principle. It has something to do with change in the velocity of light but I see no clear description of it — can you help me?"

Stokes replied by citing Huggins' 1868 paper — the very paper Airy had himself refereed!

Although Airy was acquainted with stellar spectroscopy, such observations did not fit into the mission or rhythms of daily operation of Greenwich Observatory, under his direction. Professional astronomers had little to no interest in the chemical composition of stars. Their job was to observe, map, and track their positions. As they recognized the spectroscope's power to reveal stellar motion in three-dimensional space, they became persuaded it could contribute in useful ways to their all-important sky-mapping enterprise. By 1876, even Airy had granted the spectroscope a permanent, though limited, place in the Greenwich routine.

But visual observations could never satisfy astronomers' need for precision. Instrumental instability and the faintness of a target star's spectrum made it difficult for

WHO'S WHO?

Huggins had several talented contemporaries, including astronomers, engineers, physicists, mathematicians, and more. Here's a quick roundup of some of the major players in Huggins' pursuit of stellar spectroscopy and the answers it held. —*A.K.*

George Airy (1801–1892)
British astronomer and mathematician who served as the seventh Astronomer Royal and defined the prime meridian at the Royal Observatory Greenwich, which he also directed.

Christoph Hendrik Diedrik Buijs-Ballot
(1817–1890)
Dutch meteorologist who tested Doppler's principle using musicians and a moving train.

Christian Doppler
(1803–1853)
Austrian mathematician and physicist, best known for his Doppler principle relating wavelength (frequency) to motion.

Armand Hippolyte Louis Fizeau (1819–1896)
French physicist known for his calculation of the speed of light (to within 5 percent accuracy); he discovered independently that the Doppler effect applied to electromagnetic waves.

Sidney Bolton Kincaid
(1849–1898)
Designed the Metrochrome apparatus, which allowed astronomers to reproduce the colors of stars and derive their composition.

Norman Lockyer
(1836–1920)
British astronomer jointly credited with discovering helium; he founded and edited the journal *Nature* after working as science editor of *The Reader.*

James Clerk Maxwell
(1831–1879)
Prolific Scottish physicist and mathematician known for Maxwell's equations of electromagnetism, the Maxwell-Boltzmann probability distribution, and many other concepts.

William Allen Miller
(1817–1870)
British chemist and astronomer who worked with Huggins to study the effect of a star's composition on its spectrum (in the form of absorption, or dark, lines).

Abbé Moigno (1804–1884)
Physicist, mathematician, writer, and science popularizer who published *Répertoire d'Optique Moderne* in 1850.

William Henry Smyth
(1788–1865)
British naval officer and astronomer who asked astronomers to observe double star systems to determine the origin of differing star colors.

The Orion Nebula (M42), imaged here using narrowband (Hydrogen-alpha, Oxygen-III, Sulfur-II) and RGB filters, was also a target of Huggins. Using a spectroscope, he showed that some nebulae, such as M42, display emission spectra associated with light released from gas atoms in excited states. Other "nebulae," such as Andromeda (M31, which we now know to be a galaxy), show starlike spectral characteristics. STEPHAN HAMEL

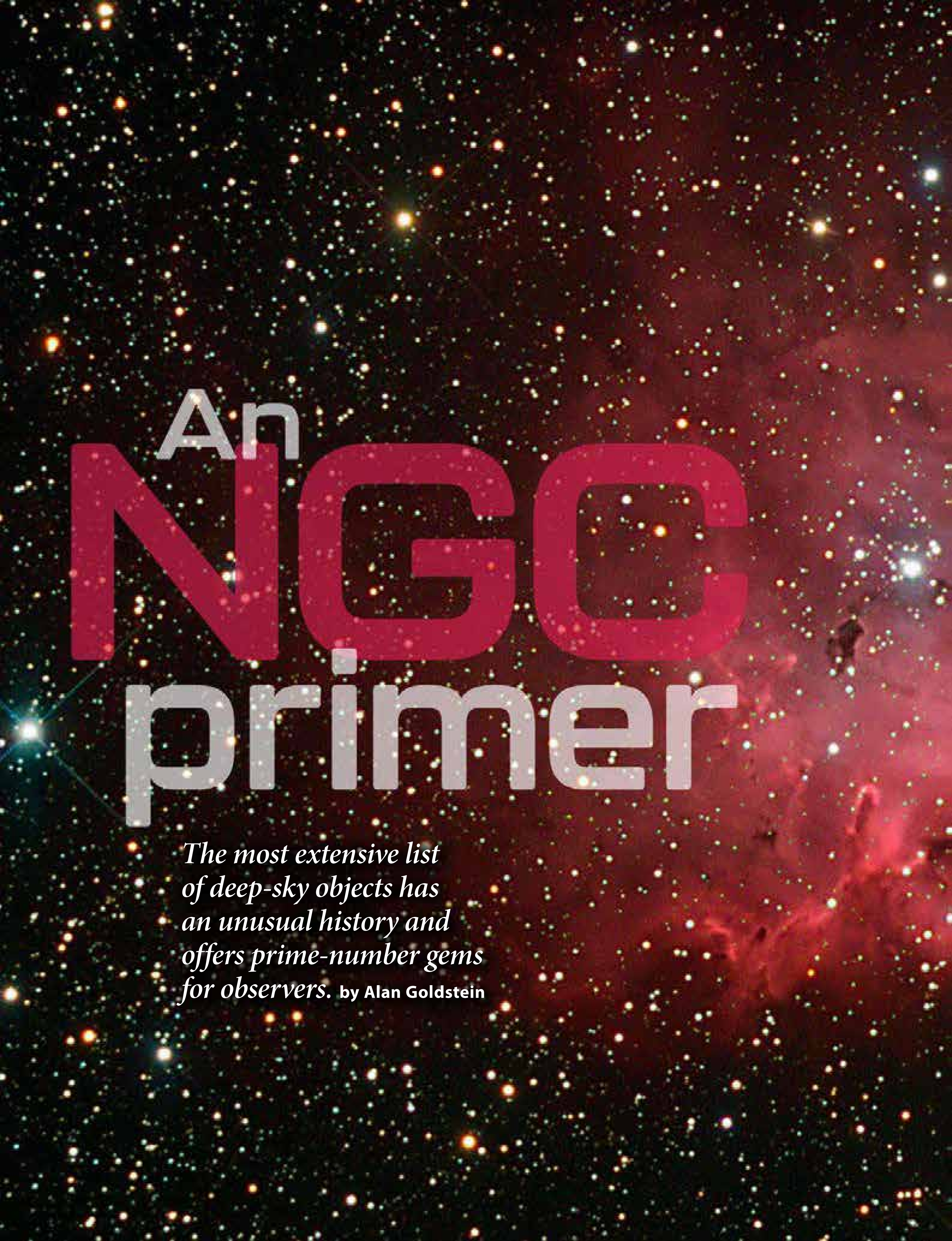
the human eye to detect the small displacements required for satisfactory measurements. After German astronomer Hermann Carl Vogel captured the first photograph of shifted stellar spectral lines in 1887, major observatories around the world became immersed in measuring the radial velocity of many different types of celestial bodies. They commissioned and purchased improved clock drives, state-of-the-art photographic equipment, and other precision instruments to aid in this work.

Private individuals could not afford such investments, and in time it became clear that Huggins had introduced a method that was well beyond his fellow amateurs' reach. While Huggins cheered the progress of his professional colleagues, he moved on to other projects.

Nevertheless, in daring to apply Doppler's principle to astronomical inquiry, Huggins gave astronomy an elegant and reliable research tool of broad utility. More importantly, he successfully persuaded his contemporaries of the method's potential. His early career as a silk merchant made him inclined to handle each and every innovation and discovery as a commodity to be packaged and sold, like an exotic bolt of cloth. He treated his colleagues like discriminating and sophisticated clientele, making every effort to instill in each a desire — even a need — to "buy" and use his newfangled methods.

As we celebrate the sesquicentennial of Huggins' introduction of Doppler's principle into the astronomer's toolkit, we commemorate the pioneering efforts of this gentleman scientist who participated with vigor and vision in the rise of astrophysics. We celebrate the risky choices he made as he moved from the periphery of scientific London toward its inner circle, choices that expose the dynamic and often uncertain process by which its boundaries of acceptable research were redefined during his lifetime. And we applaud his ability to persuade his colleagues of the theoretical authenticity, practical utility, and reproducibility of this method for measuring stellar motion in the line of sight.

Barbara J. Becker *is a retired historian of science. Her 2011 book,* Unravelling Starlight: William and Margaret Huggins and the Rise of the New Astronomy, *won the American Astronomical Society Historical Astronomy Division's 2015 Osterbrock Book Prize.*



An NGC primer

The most extensive list of deep-sky objects has an unusual history and offers prime-number gems for observers. **by Alan Goldstein**

NGC 281

This object is nicknamed the Pacman Nebula because of a prominently placed dust cloud that gives it a "mouth." BOB FERA

Any amateur astronomer who has read about the universe or has an interest in observing deep-sky objects has encountered the letters NGC. They stand for *New General Catalogue*. The complete title is *New General Catalogue of Nebulae and Clusters of Stars*.

That begs two questions: Who created the NGC? And why is it important to astronomers, professional and amateur alike? The catalog makes for a great observing list, and I am going to highlight some NGC objects that are prime numbers — thus, the primer. But first, a little historical background.

Here come the Herschels

Let's go back a couple of centuries, before the nature of the universe was known. Telescopes were small, with optics and views equivalent to a typical small telescope used by new observers today. Enter William Herschel, observer extraordinaire from England. In the 18th century, he and his sister Caroline scanned the skies and documented clusters and nebulae in a sky that was as unfamiliar to observers as the American and African continents were to explorers at the time. The true nature of objects like galaxies was unknown; they were simply amorphous clouds in the heavens, no different from the Orion Nebula (M42), the

Dumbbell Nebula (M27), or an unresolved globular star cluster.

The Herschel siblings plotted the positions of 1,000 objects and published the *Catalogue of Nebulae and Clusters of Stars* in 1786. Their observations and documentation continued; by 1810, the Catalogue was up to 2,500 objects from the skies visible from northern latitudes. Unlike the catalog of French astronomer Charles Messier, the Herschels' efforts were not connected to comet hunting.

The Herschel family did not stop documenting the heavens in the early 19th century. William's son, John, added more objects — especially with his extensive observations from South Africa. The result was a list twice as large as his father's. When published in 1864, the *General Catalogue of Nebulae and Clusters* recorded 5,079 objects.

Observers continued to add their discoveries to the astronomical world over the next 20 years. John Louis Emil Dreyer, a Danish-born astronomer, moved to Ireland and eventually became director of the Armagh Observatory, where he became the "compiler-in-chief." He gathered data from some 50 sources, chief among them the *General Catalogue*, to publish the *New General Catalogue* in 1888. For a very brief time, with 7,840 objects, the NGC listed every known nebula and cluster visible in the sky from any latitude.

Dreyer realized that the NGC was the tip of a very large celestial iceberg. More objects came to his attention in short order. He published the first volume of the *Index Catalogue* in 1895 and a second volume in 1908. Together, they indexed another 5,386 objects in the known universe. Those are recognizable from the prefix IC. For observers, IC objects tend to be more challenging. But with today's excellent optics, most are visible from dark-sky locales, given sufficient aperture.

↑ NGC 1973, NGC 1975 and NGC 1977

Part of the Orion Nebula complex, this trio consists of a glowing cloud surrounding bright, blue-white stars. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

← NGC 1097

This barred spiral is bright enough for small telescopes and sports a companion galaxy, NGC 1097A, tucked close by. R. JAY GABANY

The advent of astronomical photography brought out tens of thousands of additional objects as the 20th century unfolded. Telescope mirrors with diameters of 100 to 200 inches, coupled with improving film sensitivity, didn't render the NGC obsolete, but required newer systems of designations. Among the better known include the Shapley-Ames list of bright galaxies, Zwicky's *Morphological Catalogue of Galaxies and Clusters of*

→ NGC 457

Also known as the Owl Cluster, this birdlike formation of bright stars sparkles in small telescopes. ANTHONY AYIOMAMITIS

↓ NGC 2903

The bright galaxy in Leo has sweeping arms and a condensed nucleus. TONY HALLAS

Galaxies, Vorontsov-Velyaminov's *Morphological Catalogue of Galaxies*, Ruprecht's lists of open clusters, Perek and Kohoutek's planetary nebula list, and Sharpless' compendium of gaseous nebulae. The list goes on and on.

Taking on the NGC

Many amateur astronomers start with observing objects in the Messier catalog, but quickly expand their horizons by tackling the NGC objects. For most, the NGC catalog provides the visual observer with sufficient targets to last a lifetime.

The NGC is not perfect — far from it. It is awash with mistakes. Dreyer did not make the effort to visually confirm the existence of each object from its source; he assumed it to be accurate. As a result, there are many missing and misplaced objects. Just transpose two numbers in right ascension or declination, and the galaxy, nebula, or cluster "disappears."

American astronomer Jack Sulentic began the effort to review the accuracy of the NGC in 1964. His colleague William Tifft worked on the final effort in 1969 using the *Palomar Observatory Sky Survey* (POSS). Their first *Revised New General Catalogue of Nonstellar Astronomical Objects* was published in 1973. The RNGC was a major improvement over the NGC. Some objects rejected by Sulentic and Tifft have been located by experienced observers like American geodesist Brent Archinal, who identified things that simply didn't show up in the POSS. For example, star clusters with weak condensations were nearly invisible and blended into the background.

Eleven prime NGC objects

A primer is a book or instructions providing help. A prime is a number divisible only by 1 and itself. The NGC contains 7,840 objects, and there are 990 prime numbers within that range. By far, most are galaxies. The fewest of any type — five — are planetary nebulae.

I have selected a prime number of these, 11, for your observing pleasure. (See "Eleven NGC objects," below.) I picked the following objects

ELEVEN NGC OBJECTS

NGC Number	Object Type	Constellation	Magnitude
NGC 281	Emission nebula	Cassiopeia	—
NGC 457	Open cluster	Cassiopeia	7.5
NGC 1097	Spiral galaxy	Fornax	10.2
NGC 1973	Emission nebula	Orion	—
NGC 2903	Spiral galaxy	Leo	9.1
NGC 3079	Spiral galaxy	Ursa Major	11.5
NGC 4027	Spiral galaxy	Corvus	11.7
NGC 4649	Elliptical galaxy	Virgo	9.0
NGC 5897	Globular cluster	Libra	10.9
NGC 6781	Planetary nebula	Aquila	11.5
NGC 7027	Planetary nebula	Cygnus	10.4

← NGC 4649 and NGC 4647

NGC 4649, more commonly known as M60, is a bright elliptical galaxy in the Virgo Cluster. Its massive halo abuts the spiral galaxy NGC 4647, visible in the same telescopic field of view. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

↓ NGC 3079

This bright edge-on galaxy in Ursa Major offers fine details in a rich star field. KEN CRAWFORD

ELEVEN MORE PRIME NGC TARGETS FROM ASTRONOMY.COM

NGC Number	Object Type	Constellation	Magnitude
NGC 157	Galaxy Sbc	Cetus	10.4
NGC 751	Elliptical galaxy	Triangulum	12.5
NGC 1579	Emission nebula	Perseus	—
NGC 2237–9	Emission nebula	Monoceros	—
NGC 3389	Spiral galaxy	Leo	12.5
NGC 4051	Seyfert galaxy	Ursa Major	11.0
NGC 5189	Planetary nebula	Musca	8.2
NGC 6553	Globular cluster	Sagittarius	8.3
NGC 6709	Open cluster	Aquila	6.7
NGC 7331	Spiral galaxy	Pegasus	9.7
NGC 7789	Open cluster	Cassiopeia	6.7

because they are bright, interesting, and lie scattered across the heavens. They include clusters, nebulae, and galaxies.

○ **NGC 281**, discovered by American astronomer Edward Emerson Barnard five years before Dreyer published the NGC, is called the Pacman Nebula because a dust cloud gives it a "mouth" like the video game icon. With a small telescope, under a sky free from light pollution, you'll find it 1.7° east of magnitude 2.2 Alpha [α] Cassiopeiae.

○ **NGC 457**, a spectacular open cluster in Cassiopeia, was named the Owl Cluster in 1978 by *Astronomy* Editor David J. Eicher. This loose assemblage of stars includes a body, legs, open wings and two bright "eyes"(Phi[1] and Phi[2] Cassiopeiae), and is a wonderful sight in small telescopes.

○ **NGC 1097** is a barred spiral galaxy in Fornax. It has a high surface brightness, which makes the galaxy's arms visible in moderate apertures under dark conditions. A small elliptical galaxy companion, NGC 1097A, is reminiscent of the Andromeda Galaxy's NGC 205.

○ **NGC 1973** belongs to the Orion Nebula complex, along with NGC 1975 and NGC 1977. Together, the three objects are known as the Running Man. This bright cloud of ionized hydrogen and dust is visible with small telescopes. Light pollution filters bring out details like brightness variations throughout the cloud.

○ **NGC 2903** is one of the brightest galaxies in Leo, a spiral with a weak bar and wide sweeping arms. Messier missed it in his catalog while fainter objects made the list. The galaxy's fine detail requires larger instruments, but the hub is bright enough to spot in suburban skies.

○ **NGC 3079** in Ursa Major is a nearly edge-on spiral visible in 6-inch and larger telescopes as a thin asymmetric ray with a bright center. Its claim to fame is its proximity (¼° north) to the first gravitationally lensed quasar, QSO 0957+561, visible only through large instruments.

○ **NGC 4027** is No. 22 in Halton Arp's *Atlas of Peculiar Galaxies*. Located in Corvus, this distorted spiral galaxy is visible through small scopes. One spiral arm is much larger than the other, giving it a "C" shape. Observing structure in galaxies is not easy through small scopes, but those star systems undergoing collisions are more conspicuous than most.

○ **NGC 4649**, also known as M60, is a giant elliptical galaxy on the edge of the Virgo Cluster of galaxies. An easy

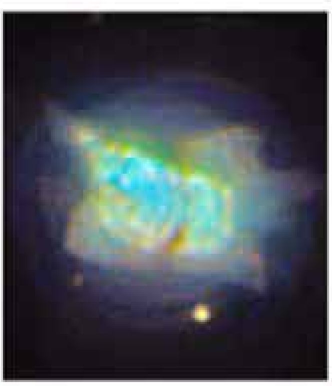
Alan Goldstein *has been observing and writing about deep-sky objects since 1976. He has been a frequent contributor to* Astronomy *since 1981.*

↑ NGC 5897

This sparse globular cluster in Libra is challenging in small telescopes, and it appears as a uniform haze sprinkled with faint stars in large backyard instruments. DEAN SALMON

→ NGC 6781

One of the sky's most unusual planetary nebulae, NGC 6781 in Aquila shows a ghostly ring of light that is brighter on one side than the other, and a faint bluish central star. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA



↑ NGC 7027

The peculiar planetary nebula in Cygnus appears boxlike in shape, its gas squeezed out around a ring of dust surrounding the central star. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

object for small telescopes, it appears as a round glow with a brighter core. With a modest telescope and better skies, look for NGC 4647, a face-on spiral galaxy practically in apparent contact. Nine Messier objects are prime-number NGCs. (See "Messier objects with NGC prime numbers," at right.)

○ **NGC 5897** is a globular cluster in Libra with a low surface brightness, making it a more challenging object than its magnitude (8.5) would suggest. It lacks the bright core common in many globulars but is relatively easy to resolve into stars.

○ **NGC 6781** rates as Aquila's best planetary nebula. Larger than Lyra's more famous Ring Nebula (M57) but more than two magnitudes fainter, it is visible in small telescopes as a ghostly disk. Modest scopes show a slightly dimmer center than the outlying ring.

○ **NGC 7027** is a compact rectangular planetary nebula in Cygnus. It is a relatively close (3,000 light-years) and young (900 years old) object of its type. Roughly 18" by 11" in extent, it has a high surface brightness, giving observers the chance to see color (blue-green) from ionized oxygen.

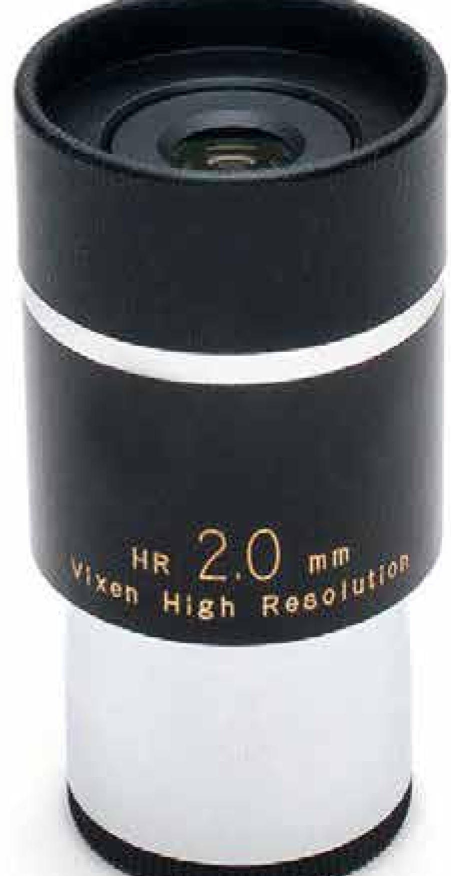
Give the NGC a workout

At 130 years old, the *New General Catalogue* is hardly "new." Yet it isn't just an anachronism from a time before photography, when the universe was fresh to observers. Tonight, whether you are using binoculars or a behemoth telescope, the NGC offers you prime opportunities to explore the heavens. Grab the opportunity to explore myriad clusters and galaxies within it. This should be your go-to catalog. Observations add a new layer to the rich observation history common to each object. Your first views should be as exciting as they were for the discoverers.

MESSIER OBJECTS WITH NGC PRIME NUMBERS

M4 (NGC 6121)
M37 (NGC 2099)
M41 (NGC 2287)
M56 (NGC 6779)
M59 (NGC 4621)
M60 (NGC 4649)
M65 (NGC 3623)
M69 (NGC 6637)
M93 (NGC 2447)

Each eyepiece in Vixen's HR line has fully multicoated optics to achieve 99.5 percent light transmission. ALL IMAGES: *ASTRONOMY*: WILLIAM ZUBACK



All HR eyepieces feature five lens elements in three groups. This arrangement produces 10 millimeters of eye relief and an apparent field of view of 42°.

These high-resolution eyepieces, specifically designed for planetary observing, minimize optical aberrations. **by Phil Harrington**

WE TEST Vixen's HR eyepieces

PICK UP ALMOST ANY BOOK that talks about telescopes, eyepieces, and magnification, and the author will probably expound the "60x-per-inch rule" or "2.4x per millimeter." This means you shouldn't pump up the magnification more than 60x for every inch of your telescope's aperture. So a 4-inch (102mm) telescope should not be pushed beyond about 240x, and so on.

I've always thought there were too many variables to come up with a rule for determining the maximum usable magnification. The key factors include the optical quality of the telescope and eyepiece; how well collimated (aligned) it is; the observer's vision; and the seeing (atmospheric steadiness). So, given excellent optics, you may be able to exceed 100x per inch on some nights, while on others, 30x per inch may cause the view to crumble.

Phil Harrington *is an equipment guru and contributing editor of* Astronomy.

Vixen Optics shares this philosophy. Because of all the high-quality telescopes available today, Vixen introduced a series of high resolution (HR) eyepieces aimed at ultra-high magnification. In most of these telescopes, each of the eyepieces violates the conventional wisdom of 60x per inch by a wide margin.

This trio of eyepieces has focal lengths of 2.4mm, 2.0mm, and 1.6mm. Yes, you read that right — an eyepiece with a focal length below 2mm. Vixen created all three for fast, top-end apochromatic refractors and Newtonian reflectors.

Optical considerations

In conventional eyepieces, such extreme focal lengths would result in eye relief distances that would be far too short for comfortable viewing. But these are anything but conventional eyepieces. Vixen's proprietary design provides 10 mm of eye relief in all three. While that can be a bit tight for those who must wear glasses, it is more than adequate for those who don't. At the same time, the apparent field of view through each is 42°.

Perhaps best of all, Vixen does all this with a minimalist design. As experienced planet-watchers will attest, less is more when it comes to viewing. Many of today's eyepieces use more than a half-dozen lens elements to render an image. Even with the finest coatings, a little bit of light scatters every time it strikes a lens surface, lowering image contrast and brightness.

The HR eyepieces consist of five elements set in three groups, all with Vixen's premium AS (Astronomy Special) coatings that claim 99.9 percent transmission. That means the ultimate throughput to the observer's eye is 99.5 percent of the light entering the eyepiece.

Have you heard of the Strehl ratio? It's a measure of the quality of an optical image against a theoretically perfect system. The higher the percentage (the closer to 1.0, or 100 percent), the better the optical design and execution. Vixen says the Strehl ratio of each HR eyepiece is 100 percent on-axis and more than 97 percent at the outer edge of the field of view. Numbers like this promise ultra-sharp images.

But there's more to these eyepieces than just outstanding optics. Vixen's designers put just as much thought into the mechanical aspects. For instance, the company painted all interior surfaces flat black to stifle unwanted reflections. Even the portion of the barrel top surrounding the eye lens is flat black to squelch any light trying to infiltrate from the side. At the other end of the barrel sits a removable baffle, also to suppress stray reflections. Unscrewing the baffle reveals standard filter threads.

Making full use of these extraordinary eyepieces requires a top-notch telescope on a night of steady seeing. For the scope end of this test, I chose my 10-inch f/5 Newtonian reflector. It consistently produces sharp images at "sane" magnifications within the limits of the 60x-per-inch rule. Would this be the case when pushed beyond its conventional limit?

Waiting for that night of steady seeing proved to be the biggest challenge. In my neck of the woods on Long Island, especially in the early spring when I was testing these, the sky is often a cauldron of turbulence due to fluctuating temperatures and strong winds. Several nights passed with unsatisfactory results until one special night in April.

Under steady air

I set up my telescope in the early evening to allow it to cool to ambient temperature, but I waited until early morning to use it, after the Moon, Jupiter, and Saturn had risen. All were positioned relatively low in the southern sky even when they were at their highest, which made seeing a concern. Fortunately, on this night, everything came together perfectly.

I began by observing the Moon, which was near Last Quarter. As soon as I swapped out one of my long-focal-length eyepieces (which I used to locate the Moon in the field of view) for the 2.4mm HR and took a peek, the only word that came to my mind was "Wow!" Viewing the lunar surface at a whopping 529x defies description. I wasn't just viewing the Moon; I was practically there orbiting it.

PRODUCT INFORMATION

Vixen HR eyepieces
Size: 1¼"
Focal lengths: 2.4mm, 2.0mm, 1.6mm
Apparent field of view: 42°
Light transmission: 99.5 percent
Eye relief: 10 millimeters
Weight: 0.3 pound (136 grams)
Price: $239 each
Contact: Vixen Optics
1050 Calle Amenecer, Suite C
San Clemente, CA 92673
949.429.6363
www.vixenoptics.com

As I toured the lunar surface, I stopped at some of my favorite ports of call, including the crater Copernicus, the Alps and Apennine mountain ranges, and Sinus Iridum. I then swapped the eyepiece for the 2.0mm (635x in my scope) and finally the 1.6mm (794x).

While the views through the 2.4mm were sharp, images through the 2.0mm were not quite as crisp due to the Moon's low altitude. The image through the 1.6mm was softer still, but incredibly impressive nonetheless. The gradual degradation of image quality is more reflective of my local seeing conditions at the time rather than the optical performance of the eyepieces.

I then moved on to Jupiter. Just the sheer apparent size of the planet was striking. It was huge! The gas giant's cloud bands were clear, showing subtle details that were not apparent through some of my long-focal-length eyepieces.

Saturn's rings were even more impressive. The Cassini Division was easy to spot, as was the subtle inner C (Crepe) ring. I suspected seeing the Encke Division, a low-contrast zone in the middle of the A ring.

More details

As I used the eyepieces, their small exit pupils intensified my eyes' floaters, those black or gray specks and strings that drift through your vision as you move your eyes back and forth. These age-related annoyances were especially apparent when I viewed the Moon.

All three HR eyepieces are nearly parfocal. That means that once you focus one, the others will require little or no refocusing when switching back and forth between them. The 2.0mm and 2.4mm were spot on, while the 1.6mm needed only a minor tweak of the fine focuser knob.

As of this writing, word has it that Vixen is about to add a 3.4mm eyepiece to the HR line. Its optical design, eye relief, and apparent field of view will match the other three.

Power to the people!

I greatly enjoyed my time with these eyepieces. Owing to the seeing where I live, the 2.4mm proved to be my favorite. If I lived in an area that offered consistently better seeing, all three would be equally valuable additions to my eyepiece case.

Do note, however, that these are definitely niche eyepieces. Their relatively narrow apparent fields, coupled with their high magnifications, do not make these the first choice for general viewing. But if you're searching for high-resolution eyepieces specifically designed for high-power lunar and planetary viewing, then Vixen's HR eyepieces are the new standard by which all others are judged.

The company threaded and blackened the inside of each eyepiece to prevent deterioration of the image. Inner baffle rings effectively stop any stray light. Even a hint of reflection that might occur on the tip of the sleeve is eliminated.

NEW PRODUCTS

Attention, manufacturers: To submit a product for this page, email **mbakich@astronomy.com**.

6-inch scope

iOptron
Woburn, Massachusetts

iOptron's Photron 150 is a 6-inch Ritchey-Chrétien reflector the company packages with its center-balanced CEM25P equatorial mount and a stainless steel tripod with 2-inch-diameter legs. It also comes with a 6x30 finder scope, a 1¼" star diagonal, a 1¼" 25mm Plössl eyepiece, and an electric focuser.

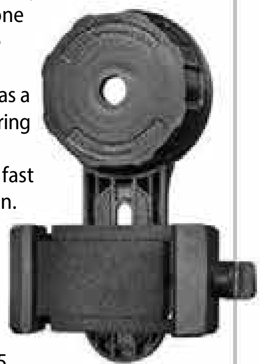
$1,498
781.569.0200
www.ioptron.com

Smartphone adapter

Orion Telescopes & Binoculars
Watsonville, California

Orion's SteadyPix Quick Smartphone Telescope Photo Adapter has a self-centering eyepiece clamp for fast installation. It will hold cellphones as large as 3¾ inches (9.5 centimeters) wide. The twist-lock eyepiece clamp is compatible with eyepieces measuring between 1 and 1¾ inches (2.5 and 4.5 cm) in diameter.

$24.99
800.447.1001
www.telescope.com



Tracking mount

Omegon
Landsberg, Germany

Omegon's Mini Track LX2 mount is a fully mechanical unit that contains no batteries or electronics. Just wind up the clockwork mechanism and it's ready to mount on a tripod. The LX2 will carry loads up to 4.5 pounds (2 kilograms). The spring system also functions as a counterweight, so no extra one is required.

129 euros
(0)8191-94049-0
www.omegon.eu

Alt-az mount

Orion Telescopes & Binoculars
Watsonville, California

Orion's VersaGo E-Series Altazimuth Mount combines a single arm mount with an adjustable tripod. The unit, which weighs 8 pounds, 5 ounces (3.8 kilograms), will support loads weighing up to 11 pounds (5 kg). You can vary the tripod's height from 36 to 57¼ inches (91 to 145 centimeters).

$99.99
800.447.1001
www.telescope.com

SEE REPORTS ON 350+ PRODUCTS AT **www.Astronomy.com/equipment.**

SECRET**SKY**

BY STEPHEN JAMES O'MEARA

Unthinkable Mars

Clear your mind the next time you look at the Red Planet.

This month I'd like you to do the unthinkable. Now that Mars is starting to shrink in apparent size as it recedes from Earth, try losing your mind before you look at the planet through your telescope. Let me explain.

Meet the "monkey mind"

During the pre-spacecraft era, many observers saw (and drew) canals on Mars. In the post-spacecraft era, it's hard to find anyone who does. I find that fascinating. Even though we know that the canals are illusory, why have observers suddenly failed to record the illusion? That could be a thought-provoking study in itself. But you could argue that, in general, both periods are separate phenomena linked to the same psychological and physiological factors that can override what is seen, and replace it with what is expected to be seen.

That's why I'm asking you to meditate — clear your mind — before you put your eye to the eyepiece. As the late Sōtō Zen monk Shunryu Suzuki alluded, it is our buzzing and thinking mind that deludes the natural mind, which is free from thought. Buddhists call this condition "monkey mind," and I wonder how much control it has over visual Mars observers today who know how the planet should appear.

Monkey see, monkey do?

Around the turn of the 20th century, it was probably more like monkey see, monkey do with Mars. For instance, after Italian astronomer Giovanni Schiaparelli introduced his *canali* to the world in 1877, Boston businessman Percival Lowell picked up the torch and carried it well into the 20th century, outperforming his predecessor by introducing hundreds of canals.

By November 1988, Valhalla had become quite diffuse and continued to fade over the years. Its remains can be seen in this Rosetta spacecraft image of Mars taken during its February 2007 flyby. ESA/MPS/UPD/LAM/IAA/RSSD/INTA/UPM/DASP/IDA

Later observers upped the ante to more than 500. Astronomers even photographed some of the canals, back in the days of grainy black-and-white emulsions. This lent a bit of credence to the visual phenomenon, breathing new life into a dying belief.

The viability of this phenomenon was even addressed by Clyde Tombaugh, the discoverer of Pluto, in a 1950 issue of *The Astronomical Journal*: "The canals cannot be entirely relegated to the realm of illusions. … The radial pattern of the canals with respect to the oases is attributed to fracturing of a thick crust under strain by the impact of asteroids which created the oases."

The author created this sketch of Mars on September 14, 1988, at the eyepiece of the 9-inch Alvan Clark refractor at Harvard College Observatory. Note the canal-like wisps extending from Sinus Meridiani, and other festoonlike features. STEPHEN JAMES O'MEARA

What I find fascinating is that Tombaugh's theory came almost five decades after Andrew Ellicott Douglass — Lowell's first assistant, who initially helped Lowell to fan the fire of the canal fervor of that period — wrote a paper in a 1907 issue of *The Popular Science Monthly*, titled "Illusions of Vision and the Canals of Mars." In it, he says, "The ray illusion [of the eye] is to me a very satisfactory explanation of many faint canals radiating from those small spots on Mars, called 'lakes' or 'oases.'" He also suggested that an astigmatic eye may see two parallel rays as double. He went on to say, "We have here the medicine to prevent this disease in the future."

Do you dare?

Actually, the "disease" of the martian canals is not about how the eye-brain system transforms the border between two high-contrast areas of differing brightness into a linear demarcation (a canal). Rather, it's about how the mind interprets what it sees, in this case waterways built by an intelligent civilization.

In August 1988, the author observed Mars with a clear mind through the 60-inch reflector at Mount Wilson Observatory. He attempted to use the eyes of a 19th-century observer to record what he saw without preconceived notions. Among the many features he drew in this regional sketch of the Mare Sirenum/Mare Cimmerium area was a striking diffuse linear streak running parallel to both maria. The author informally dubbed this feature "Valhalla." Many amateur astronomers using CCDs later recorded the long canal-like marking. STEPHEN JAMES O'MEARA

So I'm curious. Try to forget everything you know about the planet Mars, and observe it with the eyes of an early explorer. What wonders do you see? Don't try to fathom them, just accept them as they appear to you at the moment. See a canal? Excellent, go ahead and draw it. Yes, it may be illusory, but our visual world is filled with illusions, and they are wonders unto themselves.

Observing Mars without any preconceived notions cleanses the mind and helps you to enjoy the beauty of observing your Mars — no one else's. You can even keep it as your own personal secret. But if you wish to share it with me at sjomeara31@gmail.com, I promise not to tell.

Stephen James O'Meara is a globe-trotting observer who is always looking for the next great celestial event.

BROWSE THE "SECRET SKY" ARCHIVE AT **www.Astronomy.com/OMeara.**

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A PURCHASE WILL NOT INCREASE YOUR CHANCE OF WINNING.
VOID WHERE PROHIBITED.

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2. **Sweepstakes Period.** The Sweepstakes begins on August 1, 2018 at 12:00:00 a.m. Central Time, and all entries must be transmitted online no later than October 31, 2018 at 11:59:59 p.m. Central Time.
3. **How to Enter.** To enter, complete the Sweepstakes Official Entry Form online at Astronomy.com/sweeps with your name, address, city, state or province, and ZIP or postal code, and then click on the SUBMIT MY ENTRY button. You may submit only one entry through the Sweepstakes Online Entry Form during the Sweepstakes Period. However, when you submit your entry online, you will receive a link that you can share on Facebook, Twitter, or by email; you will automatically receive one additional entry for each person who enters the Sweepstakes using that link. The online entry form must be filled out completely to be eligible. This Sweepstakes is in no way sponsored, endorsed, administered by, or associated with, Facebook or Twitter. Entries from any person submitting more than the stated number will be disqualified.
4. **Prizes/Approximate Retail Value ("ARV") in U.S. Dollars. One (1) Grand Prize** consisting of Celestron Advanced VX 6" Refractor Telescope. ARV of Grand Prize: $1,439.00. **One (1) First Prize** consisting of Celestron Astro Fi 102 mm Maksutov-Cassegrain Telescope. ARV of First Prize: $429.95. **One (1) Second Prize** consisting of Celestron SkyMaster Pro 15x70 Binocular. ARV of Second Prize: $199.95. **One (1) Third Prize** consisting of Celestron Cometron 114AZ Telescope. ARV of Third Prize: $179.95. **Five (5) Fourth Prizes** consisting of a one-year subscription to *Astronomy* magazine. ARV of Fifth Prize: $42.95. TOTAL ARV of all prizes is $2,463.60.
5. **Drawing/Odds/Notification.** A random drawing for the Grand Prize, First Prize, Second Prize, Third Prize, and Fourth Prize will be held on or around November 3, 2018. Odds of winning depend on the number of entries received. Limit one prize per person. The average total circulation for *Astronomy* magazine is 95,959. Winners will be notified by email on or before November 3, 2018.
6. **Prize Restrictions.** No cash equivalent or prize substitution permitted. All prizes subject to the guarantees/warranties of the manufacturer. Any applicable federal, state, and/or local taxes are the responsibility of the winner. For prizes of $600 or more in value, winner's Taxpayer I.D. will be required to issue a Form 1099-MISC showing prize ARV as income.
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8. **Winners List.** For a list of winners, see the *Astronomy* website (Astronomy.com) after November 5, 2018, or send a stamped, self-addressed envelope to: 2018 Astro Sweepstakes Winners List, P.O. Box 1612, Waukesha, WI 53187-1612. (Residents of FL, VT, and WA may send a self-addressed envelope without the stamp.) Requests for Winners List must be received by November 5, 2018.
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BINOCULARUNIVERSE

BY PHIL HARRINGTON

The Coathanger

Check out one of the sky's best asterisms.

The Coathanger, also known as Brocchi's Cluster, is not a cluster at all, but one of the sky's prettiest chance arrangements of stars. JOSÉ J. CHAMBÓ

Not long after my childhood interest in stargazing was first sparked, my parents enrolled me in a summer astronomy program at the Stamford Museum in Connecticut. Each week, we would gather in the museum's planetarium to learn about the night sky. In between sessions, we were encouraged to view the sky both by eye alone as well as with a telescope or binoculars, if we owned one.

To help guide us at night, we were given a newsprint star atlas that showed the sky's brighter deep-sky objects plotted among the stars. The atlas was published by American Education Publications and written by the 20th century's preeminent amateur astronomer and author, Walter Scott Houston.

I kept that atlas with me whenever I went out at night that summer. It helped introduce me to the beauty of the binocular sky. While many targets seemed small and faint, one particular special pattern of stars, the Coathanger, drew my attention. It continues to be one of my favorite summer sights.

I'm not alone in that opinion. Recently, I received an email from Leilani Atwood. She wrote in part, "I thoroughly enjoy your Binocular Universe articles, and I happened to have a favorite object as well. In the constellation Vulpecula, there is an attractive grouping called Brocchi's Cluster or the Coathanger."

Have you ever seen the Coathanger? It lies inside the Summer Triangle, and it is easy to spot through binoculars, and even with the unaided eye if you know exactly where to look. Begin at Altair, the Triangle's southernmost star. Draw an imaginary line between it and the two fainter stars set to either side. Extend that line toward the northwest for about twice its length into the neighboring constellation Vulpecula. There, you should spot a tiny flock of about 10 stars.

Atwood went on to say, "When I stare straight at the cluster with just my eyes, I can only detect a few twinkles. But through binoculars, the stars are bright and easy to count. It's amazing how these stars happen to line up in such a way from our perspective on Earth."

Take a careful look through your own binoculars. The Coathanger's crossbar is drawn from six stars in a row, while another four curve away to the south, creating the hook. The wide fields of 7x to 10x binoculars give the best view, framing the Coathanger against a rich backdrop of stardust.

Historical records show that the Coathanger was known as far back as A.D. 964.

Historical records show that the Coathanger was known as far back as A.D. 964, when Persian astronomer Al-Sufi noted its misty appearance. Giovanni Battista Hodierna rediscovered the group in the mid-1600s, but it was skipped entirely by Messier and the Herschels. That was probably because the Coathanger spans 1°. It's likely that the narrow fields of their long-focal-length telescopes caused them to scan right over it unrecognized. Sorry, guys, your loss!

Of the 10 stars in the Coathanger's upside-down outline, most appear pure white through binoculars. Two, however, may show a slight yellowish or orangish glint to observers with keen color perception. The brightest star in the pattern, 5th-magnitude 4 Vulpeculae, is an orange spectral type K0 sun, while the star directly adjacent to it in the hanger's hook is a spectral type K5 star.

The Coathanger is also known as Brocchi's Cluster. In the 1920s, Dalmiro Brocchi, an amateur astronomer from Seattle, became famous for drawing detailed finder charts for hundreds of stars in the American Association of Variable Star Observers program. One particular chart showed this area in detail, capturing the group in print for the first time. It was later named in his honor. That chart also led to the Coathanger being included as Collinder 399 (abbreviated Cr 399) in the 1931 catalog of scattered open star clusters compiled by Per Collinder.

But guess what? Brocchi's Cluster isn't a cluster at all! Data gathered in 1997 by the European Space Agency's Hipparcos astrometry satellite showed it to be an asterism, just a chance alignment of random stars. They range in distance from 220 to 1,100 light-years away.

I was disappointed when I first read this, but it doesn't in any way diminish the Coathanger's sparkling beauty through binoculars. Be sure to visit it on the next clear summer's eve.

Do you have a favorite binocular target that you'd like to share? I'd love to hear about it and possibly feature it in a future column. Do as Atwood did and drop me a line through my website, philharrington.net.

Until next time, remember that two eyes are better than one!

Phil Harrington is a longtime contributor to Astronomy *and the author of many books.*


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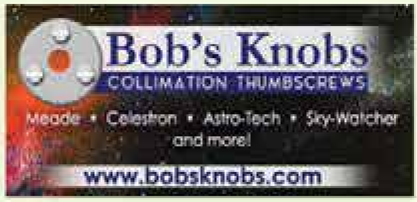
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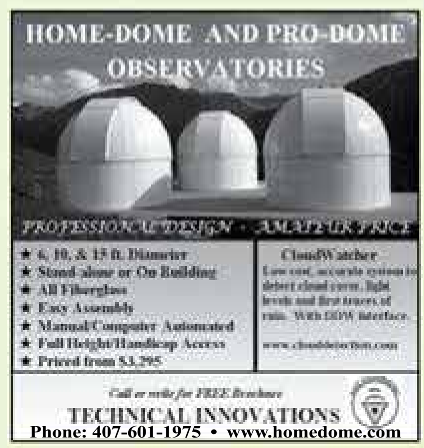
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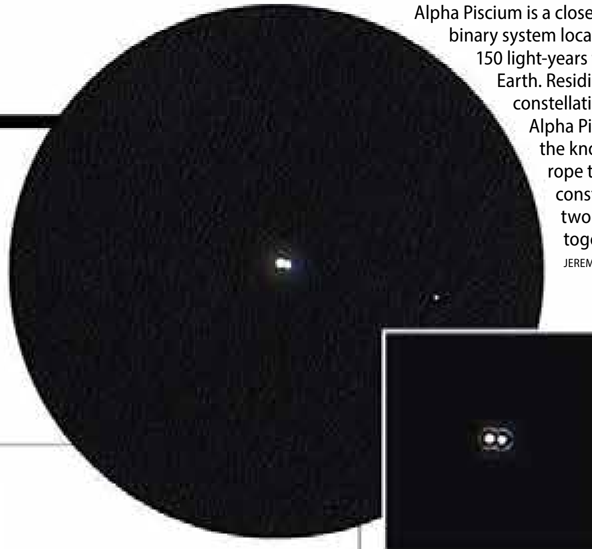
OBSERVING**BASICS**

BY GLENN CHAPLE

The Double Star Ultramarathon

Add these six stellar pairs to the standard marathon for the ultimate list.



Alpha Piscium is a close-separation binary system located about 150 light-years from Earth. Residing in the constellation Pisces, Alpha Piscium marks the knot in the rope that ties the constellation's two fish together. JEREMY PEREZ

It's time to close the books on the Double Star Marathon that I introduced in this column in March 2016. I wanted to create a double star observer's answer to the annual Messier Marathon. To that end, I compiled a matching list of 110 notable stellar pairs that are visible around the time the Messier Marathon is held. The goal, of course, was to notch all of them in a single evening.

A number of you were not interested in tackling an all-night event, instead requesting the Double Star Marathon list as a guide to the finest stellar pairs observable from mid-northern latitudes. A caveat: The list omits pairs not visible during Messier/Double Star Marathon time. Absent are a handful of notable doubles that inhabit parts of the constellations Pisces, Aquarius, and all of Fornax.

So without further ado, here are a half-dozen of the best "missing" doubles. Add them to the original list, and you have a pretty good sampling of the finest double stars visible from mid-northerly latitudes.

Zeta (ζ) Piscium (R.A. 1h14m, Dec. 7°35'; magnitudes: 5.2, 6.3; separation: 22.9")

I first viewed this amply separated pair with a 3-inch f/10 reflector and magnification of 60x. In notes that accompanied a more recent observation with a 3.5-inch f/11 refractor, I wrote, "Wide pair. Primary white; companion slightly bluish." The latter impression must have been illusory, as the secondary's F7 spectral class would indicate a soft yellow color. What colors do you see?

Alpha (α) Piscium (R.A. 2h02m, Dec. 2°46'; magnitudes: 4.1, 5.2; separation: 1.8")

This binary system has an uncertain period of more than 700 years. The pair has closed dramatically from a separation of 5.1" at the time William Herschel discovered it in 1779, to a current separation of 1.8". I've resolved this pair with a 3-inch scope at 120x, but a higher magnification is recommended for a clean split.

Omega (ω) Fornacis (R.A. 2h34m, Dec. –28°14'; magnitudes: 5.0, 7.7; separation: 1.0")

So without further ado, here are a half-dozen of the best "missing" doubles.

I have a confession: While scanning the charts in Mullaney and Tirion's *Cambridge Double Star Atlas*, I discovered that I've viewed nary a single double star in Fornax. Two are worth mentioning, and I'll be checking them out now that Fornax is in the evening sky. The component stars of Omega Fornacis appear to be relatively fixed, having shown little change in separation since a measurement made in 1836.

Alpha (α) Fornacis (R.A. 3h12m, Dec. –28°59'; magnitudes: 4.0, 7.2; separation: 5.4")

This is a notable binary star with a period of 269 years. When Herschel discovered them in 1835, the two were 3.0" apart. They closed to a tight 0.9" and then widened to their current separation of 5.4".

Zeta (ζ) Aquarii (R.A. 22h20m, Dec. –00°01'; magnitudes: 4.3, 4.5; separation: 2.3")

This binary has an uncertain period of around 500 to 600 years. In 1977, I split this near-twin system with a 3-inch reflector at 120x when the two were 1.8" apart. Currently separated by 2.3", the pair is within the grasp of a common 60mm refractor.

94 Aquarii (R.A. 23h19m, Dec. –13°28'; magnitudes: 5.3, 7.0; separation: 12.2")

This pair, easily split at a magnification of 60x, has closed slightly since a measurement made in 1821 put it at 14.2" apart. The primary sports a pale yellow hue, in keeping with its G5 spectral class.

By the way, I made one final tweak to the Double Star Marathon list. As mentioned here last March, I was debating whether to add Psi^1 (ψ^1) Piscium because it's rather low in the west around sunset at the time of the Marathon. To address the concern, I asked for reader input. Opinions were evenly split, so I assumed the role of tiebreaker.

Although I had some difficulty locating this pair low in the still twilit western sky, it was bright enough to be easily found with a low-power sweep of the target area. Moreover, Psi^1 Psc proved to be an eye-catching sight — certainly easier to spot than its nearby Messier counterpart M74. I reluctantly removed Struve 163 from the original list to make room for Psi^1 Psc.

If you'd like more double star lists, try the one the Astronomical League uses for its double star certificate program. Get the list at www.astroleague.org/files/dblstar2017.pdf. Those of you with access to back issues of *Deep Sky* magazine also can refer to issues No. 2 through 5 (spring to winter, 1983), when I showcased the finest 25 double stars for each season.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: We celebrate the autumn version of Astronomy Day with a look at #popscope. Clear skies!

Glenn Chaple has been an avid observer since a friend showed him Saturn through a small backyard scope in 1963.

BROWSE THE "OBSERVING BASICS" ARCHIVE AT **www.Astronomy.com/Chaple.**

IMAGING EXOPLANETS

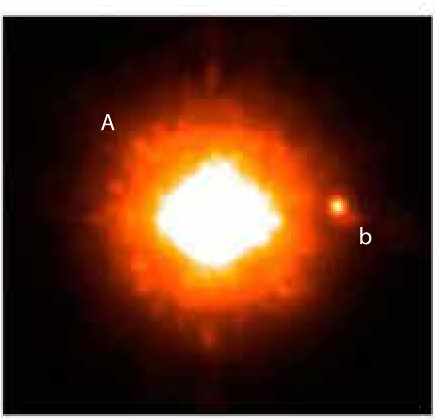
Q: EXOPLANETS THE SIZE OF EARTH CANNOT BE SEEN DIRECTLY; HOWEVER, WHITE DWARFS CAN. IS THIS DUE TO THEIR BRIGHTER APPEARANCE?

Glenn Cooperman, *Carmel Valley, California*

A: Your suspicion is right. White dwarfs, the Earth-sized remnants of Sun-like stars, are hot and bright compared with planets, which are cool and dim. Imaging planets is difficult because the planet's signal is overwhelmed by its parent star, which can be billions of times brighter.

For astronomical imaging purposes, "contrast" can be defined as the ratio of a planet's flux to its star's flux, where flux is essentially an object's apparent brightness as we see it from Earth. To image an Earth-like planet at Earth's distance from a nearby star, astronomers need an instrument capable of seeing contrasts of 10^{-10} (the contrast of the Earth-Sun system, a difference of 25 magnitudes) at a separation of 0.1". A white dwarf in a binary system is likely not only brighter, but also farther from its companion star. For example, the nearest, brightest white dwarf, Sirius B (magnitude 8.5), is a mere 10,000 times fainter than its companion Sirius A (magnitude –1.4), and currently about 10" away from it on the sky. It never gets closer to Sirius A than about eight times the Earth-Sun distance. For an exoplanet in Earth's orbit around its star at the same distance as the Sirius system — 8.6 light-years away — an astronomer's instrument would need to reach contrasts of 10^{-10} for objects separated by 0.4". (The angular separation between a star and planet is based on the planet's distance from the star, its eccentricity, and the system's distance from Earth.)

The current list of directly imaged exoplanets contains objects several times Jupiter's mass and about 10 to 100 times farther from their stars than Earth is from the Sun. Many of these planets are extremely young and still generating some heat — and thus, light — of their own as they form and contract. Some may even be brown dwarfs. None of these approaches Earth-sized planets. They were imaged by blotting out the parent star's light; this technique still has significant limitations, but astronomers are working hard to push it to spot fainter, smaller, and closer-in planets.



We cannot yet directly image Earth-sized planets. GQ Lupi (A) has a substellar companion (b) 250 times fainter than the star itself, orbiting about 0.7" away, or 100 times the Earth-Sun separation. The companion's radius is between three to six times that of Jupiter. Its mass may be up to 30 times Jupiter's mass, placing it in possible brown dwarf territory. ESO

Alison Klesman
Associate Editor

Globular clusters such as M5 maintain their shapes because their stars have angular momentum as they orbit the cluster's center. ESA/HUBBLE AND NASA

Q: IN THE MAY ISSUE, PHIL HARRINGTON SAYS M5 "MAY CONTAIN AS MANY AS 500,000 STARS CRAMMED INTO A SPACE ABOUT 165 LIGHT-YEARS ACROSS." WHY DON'T THEY ALL COALESCE INTO ONE GIANT STAR?

David Pippin
Dearborn, Missouri

A: Globular clusters are old objects; for example, M5 is about 13 billion years old. Such advanced age indicates they are stable, which seems at odds with the idea that over time, the gravitational influence of all those stars crammed in so small a space should cause the entire thing to collapse.

The key is that a globular cluster's stars are all moving, orbiting the cluster's center of mass. The energy of that motion — specifically, each star's angular momentum — offsets the gravitational pull of all that mass and prevents the stars from falling toward the center and coalescing. When you average out all these orbits, they're essentially random, which is why the cluster appears spherical.

Globular clusters do, in fact, evolve. Over time, gravitational interactions between two passing stars can "pass" angular momentum from one to the other, with more massive stars donating energy to those that are less massive. This leads to two effects: The first is mass

segregation, which causes more massive stars to fall toward the center, while less massive stars are boosted toward the cluster's outer edges. The second is evaporation — stars can be shot out of the cluster altogether. This process could, over extremely long timescales, cause the cluster to fly apart, rather than coalesce, as it loses more and more total mass to ejected stars.

Alison Klesman
Associate Editor

Q: IF A TABLESPOONFUL OF A NEUTRON STAR WERE PLACED ON EARTH'S SURFACE, WHAT WOULD HAPPEN?

Caroline Adams
Portland, Oregon

A: Before we can know what happens when our spoonful of neutron star comes to Earth, let's think about what's in our spoon: a superdense collection of neutrons.

A neutron star is the remnant of a massive star (bigger than 10 Suns) that has run out of fuel, collapsed, exploded, and collapsed some more. Its protons and electrons have fused together to create neutrons under the pressure of the collapse. The only thing keeping the neutrons from collapsing further is "neutron degeneracy pressure," which prevents two neutrons from being in the same place at the same time.

Additionally, the star loses a lot of mass in the process and winds up only about 1.5 times the Sun's mass. But all that matter has been compressed to an object about 10 miles (16 kilometers) across. A normal star of that mass would be more than 1 million miles (1.6 million km) across.

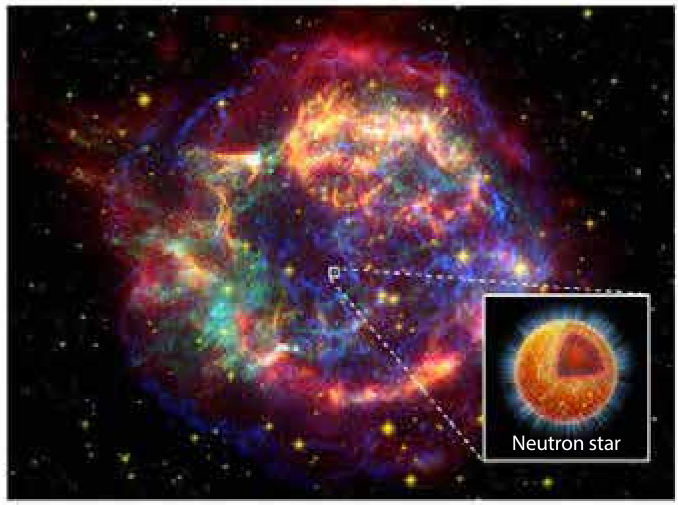
A tablespoon of the Sun, depending on where you scoop, would weigh about 5 pounds (2 kilograms) — the weight of an old laptop. A tablespoon of neutron star weighs more than 1 billion tons (900 billion kg) — the weight of Mount Everest. So while you could lift a spoonful of Sun, you can't lift a spoonful of neutron star.

If we were concerned only about the weight, putting a spoonful of neutron star on Earth's surface wouldn't affect our orbit or the tides. It's like adding another mountain. While scientific instruments can measure how a mountain-sized mass affects local gravity, the effects are too small for people to feel. So unless you stood right next to the spoon, you wouldn't notice.

However, we're not just worried about the mass in the spoon. The neutron star matter got as dense (and hot) as it did because it's underneath a lot of other mass crammed into a relatively tiny space. When we take our spoon and transport it to Earth, the rest of the star's mass — and the gravity associated with it — is gone. Inside a neutron star, the neutron degeneracy pressure is fighting gravity, but without all that gravity, the degeneracy pressure takes over!

Imagine you have a can of soda, and it's all shaken up. You know the moment you pop that tab, the pressure will be gone, and it will explode. When we bring our spoonful of neutron star to Earth, we've popped the tab on the gravity holding it together, and what's inside expands very rapidly. A spoonful of neutron star suddenly appearing on Earth's surface would cause a giant explosion, and it would probably vaporize a good chunk of our planet with it.

Valerie Mikles
National Oceanic and Atmospheric Administration Contractor, Quality Assurance, I.M. Systems Group, College Park, Maryland



Neutron stars are incredibly dense objects about 10 miles (16 km) across. Only their immense gravity keeps the matter inside from exploding; if you brought a spoonful of neutron star to Earth, the lack of gravity would cause it to expand rapidly. X-RAY: NASA/CXC/UNAM/IOFFE/D.PAGE, P. SHTERNIN ET AL; OPTICAL: NASA/STScI; ILLUSTRATION: NASA/CXC/M. WEISS

Q: IN THE APRIL ISSUE, MICHAEL RAMPINO WROTE ABOUT CYCLES OF COMET COLLISIONS WITH EARTH EVERY 26 MILLION TO 30 MILLION YEARS. IS THERE EVIDENCE OF CYCLICAL BOMBARDMENT ON OTHER PLANETS OR MOONS?

Robert Harrison
Albuquerque, New Mexico

A: On Earth, the age of a crater can be measured in several ways, with varying degrees of accuracy. Dating the sediments that appeared earliest after the event, or the youngest rocks targeted by the impactor, gives a rough estimate of a crater's age. Alternatively, some craters can be more accurately dated using the decay of radioactive elements in the rocks melted by the impactor.

The 26 million- to 30 million-year cycle noted is based on several analyses of different craters around the globe. We can date craters on Earth using these methods because we have direct access to them.

The impact cratering histories of the Moon and the other planets in the solar system are not known well enough to look for cycles. In one attempt to find cycles, samples of lunar soil were analyzed by scientists at the University of California, Berkeley. Their work was published March 10, 2000, in the journal *Science*.

By dating tiny glass spherules — microscopic beads of glass produced from rocks melted by lunar impacts — in the soil, they determined that the rate of asteroid impacts on the Moon (and presumably on Earth as well) has increased in the last billion years, but they could not detect any cyclical changes.

Michael Rampino
Professor of Biology, New York University, New York

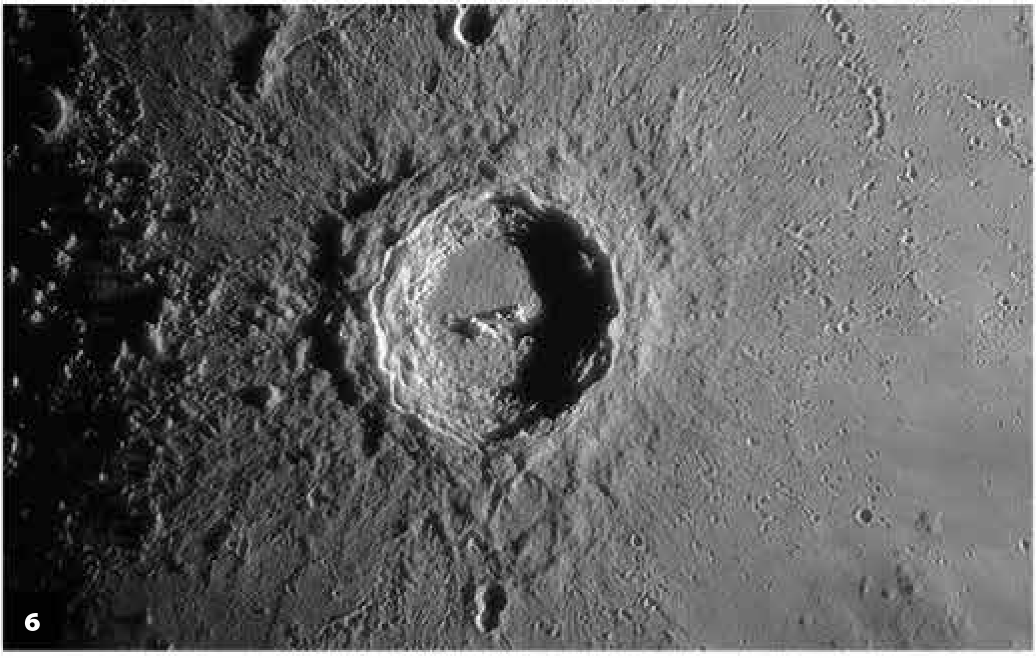
Send us your questions

Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

READER GALLERY

1. NORTHERN STAR TRAILS
Star trails mingle with a tree's branches in this 2-hour exposure taken April 3, 2018, near Springfield, Oregon. The photographer used a 7.5mm lens. ***• Dave Horton***

2. SMOKE AND MIRRORS
Reflection nebulae abound in this image. NGC 6726 and NGC 6727 form the cloud to the right. Above and to the left of them is NGC 6729, which also contains some reddish emission nebulosity. Another dusty, reflective cloud, IC 4812, surrounds the gorgeous, blue double star at lower left. ***• Warren Keller***



3. ALMOST TOO BRIGHT
Mars (the brilliant orange-white spot) shines at magnitude 0.5 as it passes between the Lagoon (M8, bottom) and Trifid (M20, top) nebulae March 18, 2018. By the time it reached its peak July 27, the Red Planet blazed more than nine times brighter.
• *Damian Peach*

4. NOT BORING AT ALL
Most amateur astronomers will tell you that elliptical galaxy M89 is fairly boring to look at. But stack 960 minutes of exposures taken through a 17-inch telescope, and you get a much different picture! Beyond the main target, look at all the distant galaxies visible. **• *Mark Hanson***

5. SEVEN STARS FOR SEVEN BROTHERS
Although known in the West as the Big Dipper, these same stars were the Seven Brothers in ancient Persia. Here we see them rising above the snow-covered Alborz mountain range in Iran.
• *Jianfeng Dai*

6. DEVIL'S IN THE DETAILS
Copernicus Crater looks terrific in this February 24, 2018, compilation taken near Columbia, South Carolina. The photographer captured 9,000 frames of video through a Baader blue filter, out of which he selected the best 300 to create this image. **• *Brian Ford***

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BREAK
THROUGH

Diving into the Lagoon

Although the Milky Way's spiral arms teem with pockets of intense star formation, few of these stellar nurseries can match the frenzied activity in the Lagoon Nebula (M8). This recent Hubble Space Telescope photo homes in on the nebula's central region, 4 light-years across. Here, dense pockets of gas and dust collapse under their own weight to form new stars. The most impressive of these newborns, Herschel 36, peeks through the dust at center. This behemoth is 32 times more massive, eight times hotter, and 200,000 times more luminous than our Sun. NASA/ESA/STScI

MARTIN GEORGE describes the solar system's changing landscape as it appears in Earth's southern sky.

November 2018: Changing of the guard

Venus and Jupiter dominated the evening sky for more than half of 2018, but with Venus gone and Jupiter on its last legs, evenings now have a decidedly different flavor. The month kicks off with the biggest and smallest planets huddled together in the twilight glow.

Jupiter stands out largely because it is so bright. Shining at magnitude –1.7, the giant world hangs some 10° above the western horizon 45 minutes after sunset. Jupiter resides in Libra, though you'll be hard-pressed to see this constellation's dim stars in twilight. The planet dips lower with each passing night and disappears by midmonth as it approaches a November 26 conjunction with the Sun. It will return to view before dawn in December.

Look at Jupiter through binoculars November 1, and you'll spot **Mercury** 4° to its upper left. The tiny planet glows at magnitude –0.2, four times dimmer than its neighbor. Unlike Jupiter, however, Mercury pulls away from the Sun with each passing day and becomes easier to see. The inner planet reaches greatest elongation on the 6th, when it lies 23° east of our star and appears nearly 15° high 45 minutes after sundown.

At greatest elongation, Mercury hangs 3.5° below 1st-magnitude Antares, the brightest star in Scorpius the Scorpion. Three days later, the planet slides less than 2° north (lower right) of the ruddy star with a slender crescent Moon appearing nearby. Mercury is already on its way back toward the Sun, however, and it disappears from view after midmonth, reaching inferior conjunction November 27.

If you look well above and to the right of Mercury, you can't help but spy **Saturn**. The ringed planet appears as an obvious interloper set against the backdrop of Sagittarius. At magnitude 0.6, Saturn shines far brighter than any of the constellation's stars.

The planet stands high enough after nightfall for observers to get good looks through their telescopes. In mid-November, the planet's disk spans 15" while the ring system extends 35" and tilts 26° to our line of sight. A 5-centimeter instrument provides enough aperture to see the Cassini Division — the dark gap that separates the outer A ring from the brighter B ring — during moments of good seeing.

The best-positioned evening planet is ruddy **Mars**. The Red Planet lies two-thirds of the way to the zenith in the northwestern sky as twilight fades. And it remains far brighter than any nearby star, even though it dims from magnitude –0.6 to –0.1 during the month. The planet's eastward motion against the starry backdrop carries it from Capricornus into Aquarius on November 11.

Mars' apparent size shrinks in tandem with its brightness. A telescope shows a 12"-diameter disk in early November that drops to 9" across at month's end. This is still big enough to show some subtle surface features, but the good views won't last much longer.

Although **Venus** passed between the Sun and Earth in late October, it quickly returns to view before dawn. It already appears conspicuous by November 15, when it shines at magnitude –4.7 and stands nearly 10° high in the east 45 minutes before sunrise. You also might see 1st-magnitude Spica, the brightest star in Virgo, just 1° to Venus' upper left. The planet grows even more prominent as the month progresses. On the 30th, it appears some 6° higher and blazes at magnitude –4.9.

November is also a great month to view Venus through a telescope because it displays a large disk and a pleasing crescent phase. On the 15th, the planet appears 52" across and just 11 percent lit. By the 30th, Venus spans 41" and the Sun illuminates one-quarter of its Earth-facing hemisphere.

The starry sky

I often make a point to the audiences in my planetarium that few constellations actually look like the object or creature after which they are named. Some do, of course — Crux the Cross, Scorpius the Scorpion, and Orion the Hunter are all recognizable. But no resemblance at all exists at the other end of the scale. I would place the rather dim constellation Sculptor the Sculptor firmly in this category.

Sculptor passes nearly overhead on November evenings. You can find its approximately rectangular shape between Beta (β) Ceti and Alpha (α) Phoenicis. French astronomer Nicolas Louis de Lacaille introduced this constellation in the mid-18th century.

Despite the constellation's obscurity, a telescope reveals several worthwhile objects. The Silver Coin Galaxy (NGC 253) ranks among the sky's brightest showpiece galaxies. I have found it quite easily through 7x50 binoculars under a dark sky. A 20-cm or larger telescope reveals this edge-on spiral galaxy as a thin streak of light. Even better, NGC 253 is pretty easy to find. Draw an imaginary line from Alpha Sculptoris to Beta Ceti. The galaxy lies a little west of a point 40 percent of the way along this line.

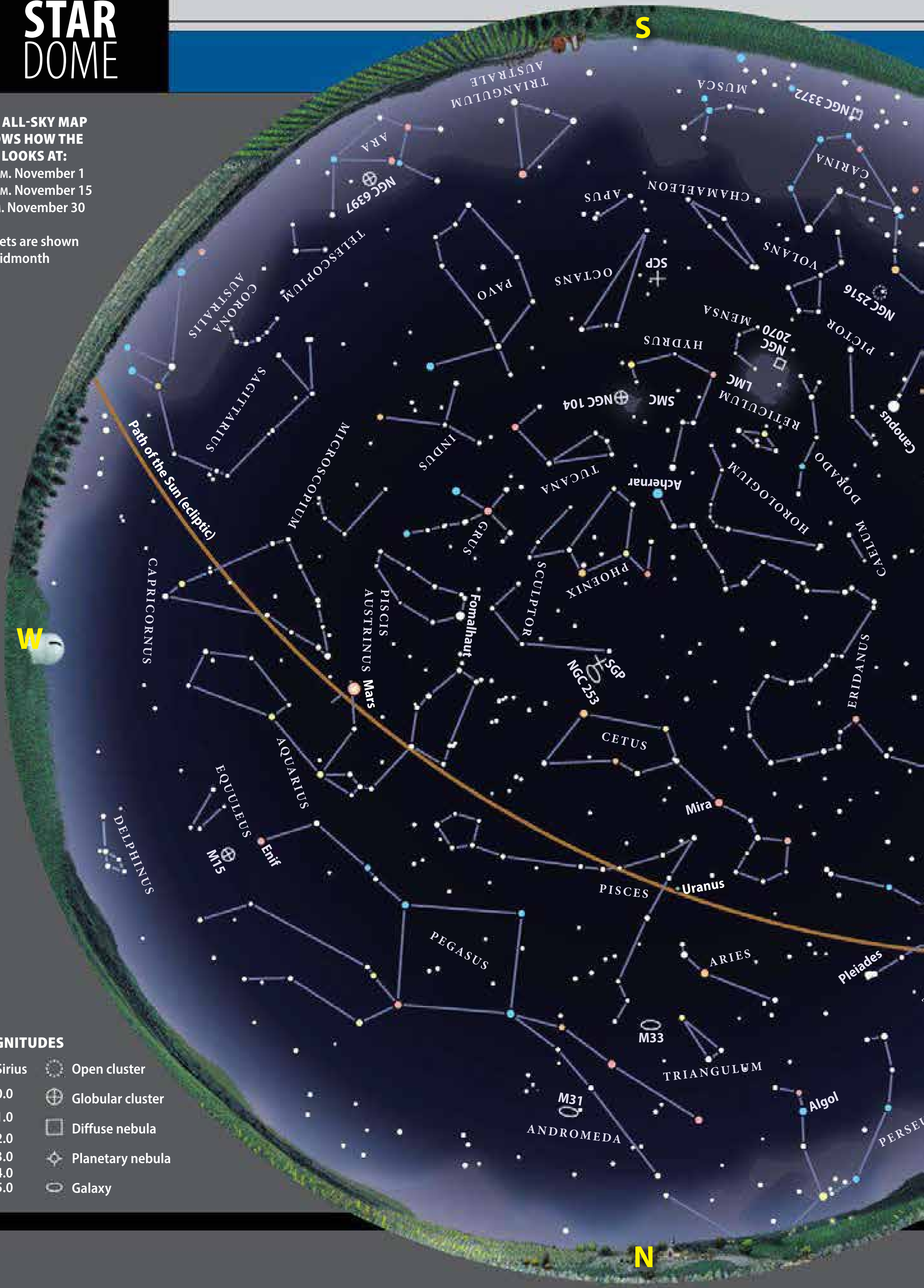
NGC 253 belongs to the Sculptor Group of galaxies, one of the closest such systems to our Local Group. A second member of this collection is also worth targeting through your scope. NGC 55 lies on Sculptor's border with Phoenix, just under 4° north-northwest of Alpha Phe. Through a 20-cm instrument, this spiral galaxy appears rather misshapen with a bright part at one end.

Sculptor also contains some interesting double stars, though many of them are too close to split easily through small scopes. Perhaps the constellation's best double is Lalande 192, which lies 1.6° northeast of Delta (δ) Scl. Coincidentally, it also goes by the designation Dunlop 253 — the same three-digit number as the galaxy NGC 253 — from the double star catalog of James Dunlop. Lalande 192's stars shine at magnitudes 6.8 and 7.4, with a gap of 6.6" between them.

STAR DOME

THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:
11 P.M. November 1
10 P.M. November 15
9 P.M. November 30

Planets are shown at midmonth



MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

HOW TO USE THIS MAP: This map portrays the sky as seen near 30° south latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

STAR COLORS: Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white without optical aid.

Illustrations by *Astronomy*: Roen Kelly

NOVEMBER 2018

Calendar of events

6 The Moon passes 10° north of Venus, 2h UT

Mercury is at greatest eastern elongation (23°), 15h UT

7 New Moon occurs at 16h02m UT

9 Mercury passes 1.8° north of Antares, 6h UT

The Moon passes 7° north of Mercury, 12h UT

11 The Moon passes 1.5° north of Saturn, 16h UT

12 The Moon passes 0.9° north of Pluto, 18h UT

14 Venus is stationary, 3h UT

The Moon is at apogee (404,339 kilometers from Earth), 15h56m UT

15 First Quarter Moon occurs at 14h54m UT

16 The Moon passes 1.0° south of Mars, 4h UT

17 Mercury is stationary, 5h UT

The Moon passes 3° south of Neptune, 6h UT

Asteroid Juno is at opposition, 22h UT

Leonid meteor shower peaks

20 The Moon passes 5° south of Uranus, 20h UT

23 Full Moon occurs at 5h39m UT

25 Neptune is stationary, 8h UT

26 Jupiter is in conjunction with the Sun, 7h UT

The Moon is at perigee (366,620 kilometers from Earth), 12h12m UT

27 Mercury is in inferior conjunction, 9h UT

30 Last Quarter Moon occurs at 0h19m UT

A+ BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**